jpl

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

750-13

PHOTOHELIOGRAPH
STRUCTURE, MOUNTING, AND
MECHANISMS

August 12, 1968

E. H. Rehnborg

Approved by: J Denton Allen

J. Denton Allen, Task Leader,
Photoheliograph Task

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

FOREWORD

This report covers work on one phase of the photoheliograph development task, NASA Code 945-84-00-01-00, for the period November 1967 through June 1968. The photoheliograph has been proposed to NASA for the Apollo telescope mount (ATM) by Caltech, with Professor Harold Zirin as the principal investigator and Dr. Robert Howard of Mt. Wilson and Palomar Observatories the co-investigator (see TM 33-369, November 1967). The objective of the investigation is to obtain high resolution cinematographs in white light near ultraviolet and narrow band hydrogen alpha. Because of the ATM program uncertainties, emphasis has been placed on areas of technology that are somewhat mission-independent, but the ATM spacecraft has been used to establish design constraints.

ABSTRACT

Design and analysis work has progressed to a point where the photoheliograph structure, supports, mountings and mechanisms are now being detailed for prototype fabrication. The basic telescope structure consists of a central truss-type housing which is mounted to the ATM spar. To this housing are attached demountable subassemblies containing the primary mirror and launch locks, the secondary mirror system and realignment mechanisms, and the camera-filter cluster. All components are being stress checked for the maximum anticipated launch loads. This includes the basic structural members as well as the locks and clamps which immobilize and support the mechanisms during launch. Additionally, thermal analyses are being performed for both operating and unusual conditions (such as dark-side standby, off-axis search for the sun, etc.). The results have, in certain cases, changed or modified the materials which were selected on the basis of loads and weights. Detailed design work is continuing with the object of early fabrication of critical components for environmental testing. Principally among these are the primary mirror mounting cell and the mechanisms for alignment and focus.

CONTENTS

FIGURES

CONTENTS (contd)

FIGURES (contd)

PHOTOHELIOGRAPH STRUCTURE, MOUNTING, AND MECHANISMS

GENERAL DESCRIPTION

The photoheliograph configuration that has now been selected for detail design is shown in Fig. 1. It consists of primary mirror assembly, secondary mirror assembly, the housing and mounting structure, the camera cluster, and various accessories. The telescope proper is mounted in one of the four quadrants of the ATM as shown in Fig. 2. This fills the quadrant to capacity and, in fact, requires the removal of some of the spar insulation to keep the housing from extending too far beyond the boundary cylinder circumscribing the spar. The best fit still requires special spar corner braces for this quadrant. The camera cluster will be located in the adjacent quadrant because of the additional space needed. The proposed ATM-B experiments have been listed by the Bendix-Martin group and these can still be properly mounted in the ATM. Fig. 2 shows the envelope of each piece of equipment.

For structural integrity, all subassemblies of the photoheliograph are attached directly to the housing, and only the housing is attached to the spar. Clearance holes through the spar are required for the components in the adjacent quadrant—the light tube, camera rack, and alignment sensor. The assembly is mounted on the ATM spar at three points, two of them are on the primary cell and the third is at the secondary end of the housing. These mounts are designed so that differential expansion of the spar, distortions due to launch loads, or thermal deflection of the spar will not load the telescope housing and hence will not produce any alignment errors of the mirror surfaces relative to each other (See Fig. 3). Pointing may be shifted relative to the ATM center line due to these thermal distortions or as a result of launch loads. The spotting scope, however, and the monitoring vidicon systems will identify the target, and differences in pointing between the photoheliograph and the ATM fine sun sensor can be compensated for by the astronaut.

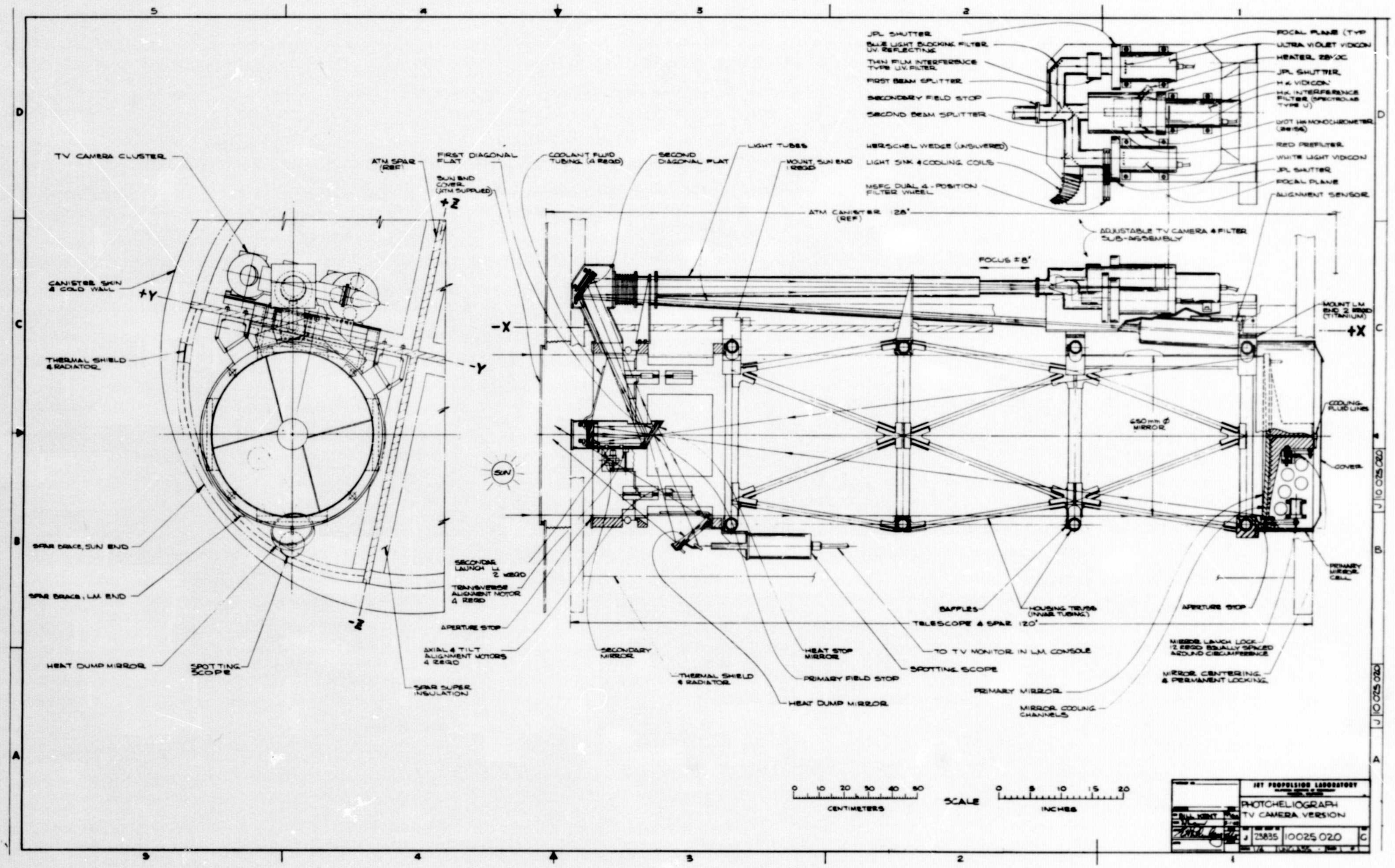


Fig. 1. Photoheliograph, TV camera version

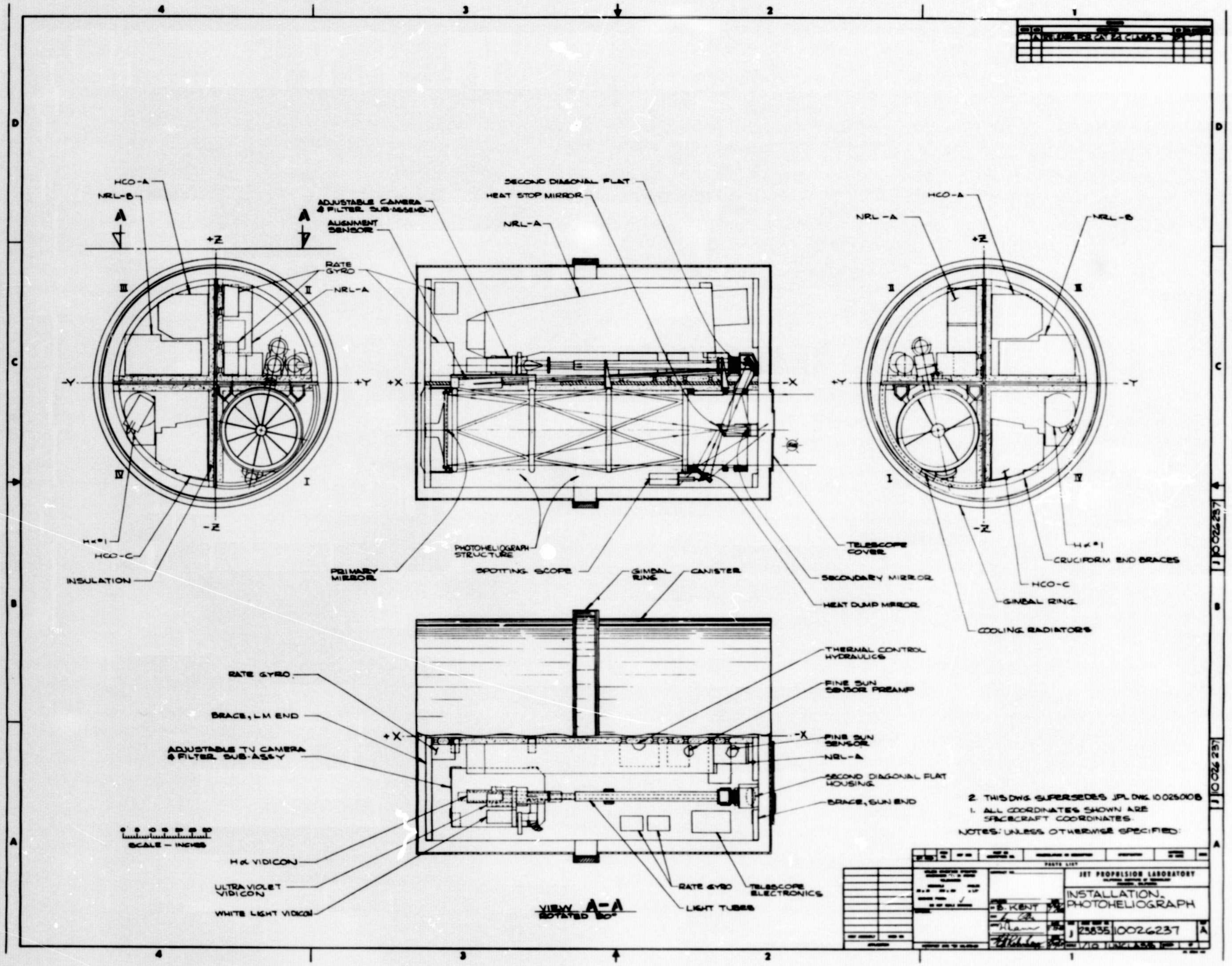


Fig. 2. Installation

3

750-13

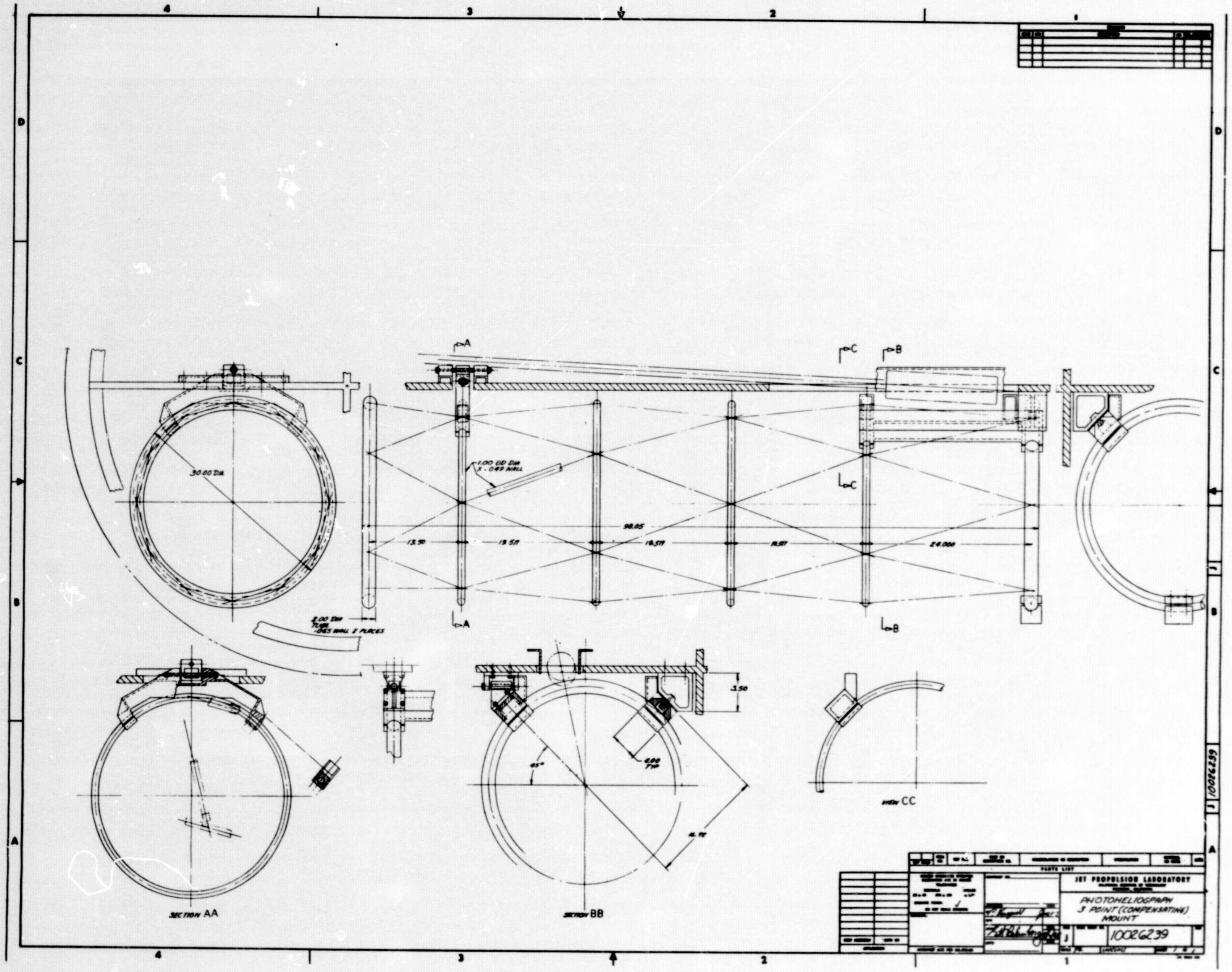


Fig. 3. Housing

As installed in the ATM, the restraint of heat transfer to or from the spar have been considered by (1) selecting low-conductivity materials for the mounts, (2) retaining at least one inch of super insulation on the spar at the points where the housing structure comes close, and (3) wrapping the telescope with a thermal insulating blanket. The operating temperature of the telescope structure will be approximately 75°F with the active cooling system running. The insulation provisions, plus the fact that excess solar energy is effectively dumped directly to space, will properly restrict the heat transfer to the ATM spar.

Over one quadrant, the ATM canister cold wall faces the thermal control radiator for the active cooling system. The radiator is attached to the spar along either side, to the telescope along the center, and to the spar corner braces at each end. The radiator is basically a plate to which a grid pattern of tubing is attached (similar to the canister cold wall) which conducts the cooling fluid from the telescope to the pump and accumulator. Stiffeners will be added as necessary, but as this structure needs only to be self-supporting, elastic flexibility during launch will not be a problem.

Each component of the photoheliograph structure has been or is being stress-analyzed for a 50g static equivalent of the combined launch modes of steady acceleration plus vibration plus acoustic energy (Appendix C). As the weight limitation does not allow each member to be heavy enough to insure no distortion as a result of these launch loads, the design incorporates several realignment mechanisms which may be operated by the astronaut, either remotely or manually, once the ATM is in orbit. Primarily, these included two sets of motor-gear assemblies which can adjust the secondary assembly in all 6 degrees of freedom.

The reference is the alignment sensor which is mounted rigidly to the primary mirror cell. The tolerances on the orientation and distance of the sensor from the optical axis has been specified in detail (Document 750-8). These are necessary in order to be able to rely on the alignment sensor for in-flight realignment of the secondary assembly. At least one realignment is mandatory — the initial one following release of the launch locks. (See later discussion on Secondary Assembly.)

During launch, the telescope aims downward and all moveable items are held securely by launch locks. These include sets at the primary mirror, the secondary assembly, and the moveable camera cluster. The ATM canister provides a dust-tight door; contamination within the ATM is prevented from entering the telescope by a flexible collar running from the secondary assembly ring to the canister end plate. The detailed structure, adjustment mechanisms, and launch locks are described in the following sections.

REQUIREMENTS (Figs. 1 and 2)

One of the two basic specifications for the mechanical design of the photoheliograph is the Functional Requirements Specification by Professor Zirin. The requirements of the number of cameras and the operating wavelengths and the bandwidth for each of them are obtained from this specification. These data, in turn, determine the dimensional stability requirements, the exposure time, the vibration level that can be tolerated in operation, and the tolerable vibration level that can be generated with the thermal control system and motors. This specification also controls the minimum acceptable size of the telescope. The upper limit is determined by the space available in the spacecraft. The dimensions of the subassemblies and the weight of the components are determined from this information. The specification also specifies the alignment control and the realignment capabilities which affect the structure. All of these data determine the requirements for launch locks. The size, weight, and movement (control and alignment movement) of the various components establishes the component strength which determines the requirements for launch locks. Basically, the Functional Requirements Specification determines the telescope outline.

The second specification is the Marshall Spaceflight Center Environmental Design and Test Criteria. This specification lists the temperature, launch vibration, acceleration, and acoustic levels. It further specifies the heat transfer—the method to be used for cooling and the allowable heat load to be dissipated. From conferences with Marshall, Bendix and Martin-Marietta, the limitations on telescope size, weight, and mounting location in the ATM were ascertained. This information controlled the outside diameter, the length, the accessory protuberances, and the method of mounting to the spar.

The conferences also indicated the arrangement of the thermal control radiator and the location of the camera cluster. The final configuration has not been compromised structurally or mechanically. Changes, if any, for mounting on a different spacecraft would be accessory locations and mounting attachments. See Figs. 1 and 2.

The location of the camera cluster in the adjacent quadrant will not be a problem during assembly in the ATM because (1) notches can be made in the spar so that the camera rack can be preassembled to the telescope and the assembly inserted into the spar, (2) the light tube is non-critical and can be added later by mounting to the housing through access holes, and (3) the alignment requirements of the cameras are not very restrictive. The light beam coming down toward the cameras is approximately 5 cm in diameter. As long as there is a full frame within that beam, it is a matter of mental calibration to determine what is being photographed. This can be verified by the monitor white light vidicon located with the film cameras or by the real time display if vidicons are used. The full camera frame is about 2-1/2 cm. The large beam allows some motion of the secondary assembly during realignment without losing the picture, i. e., without the beam sweeping past the frame. The spotting telescope serves only for rough spotting; fine detail cannot be seen through it and it merely gives an indication of where the telescope is pointed on the face of the sun. The final verification of the aiming is with the monitoring vidicons.

The interface with the ATM places no restriction on how the photoheliograph is attached to the spar, providing that there is no interference with any other experiment and no compromise of the super-insulation provided for the spar. The generally accepted mounting method is a three-point compensating suspension, so that the mounting is rigid but does not load or distort the housing if the spar should distort. That is, each mounting is free in some directions, but holds in the others. See Figs. 3, 4, and 5.

The interface of the photoheliograph with the ATM or other spacecraft support includes thermal, mechanical, electrical, and optical considerations. The thermal interface consists of the heat-transfer restrictions to the support structure and to space. The latter, in the ATM, means radiation to the canister coldwall. The mechanical interface includes the mounting provisions,

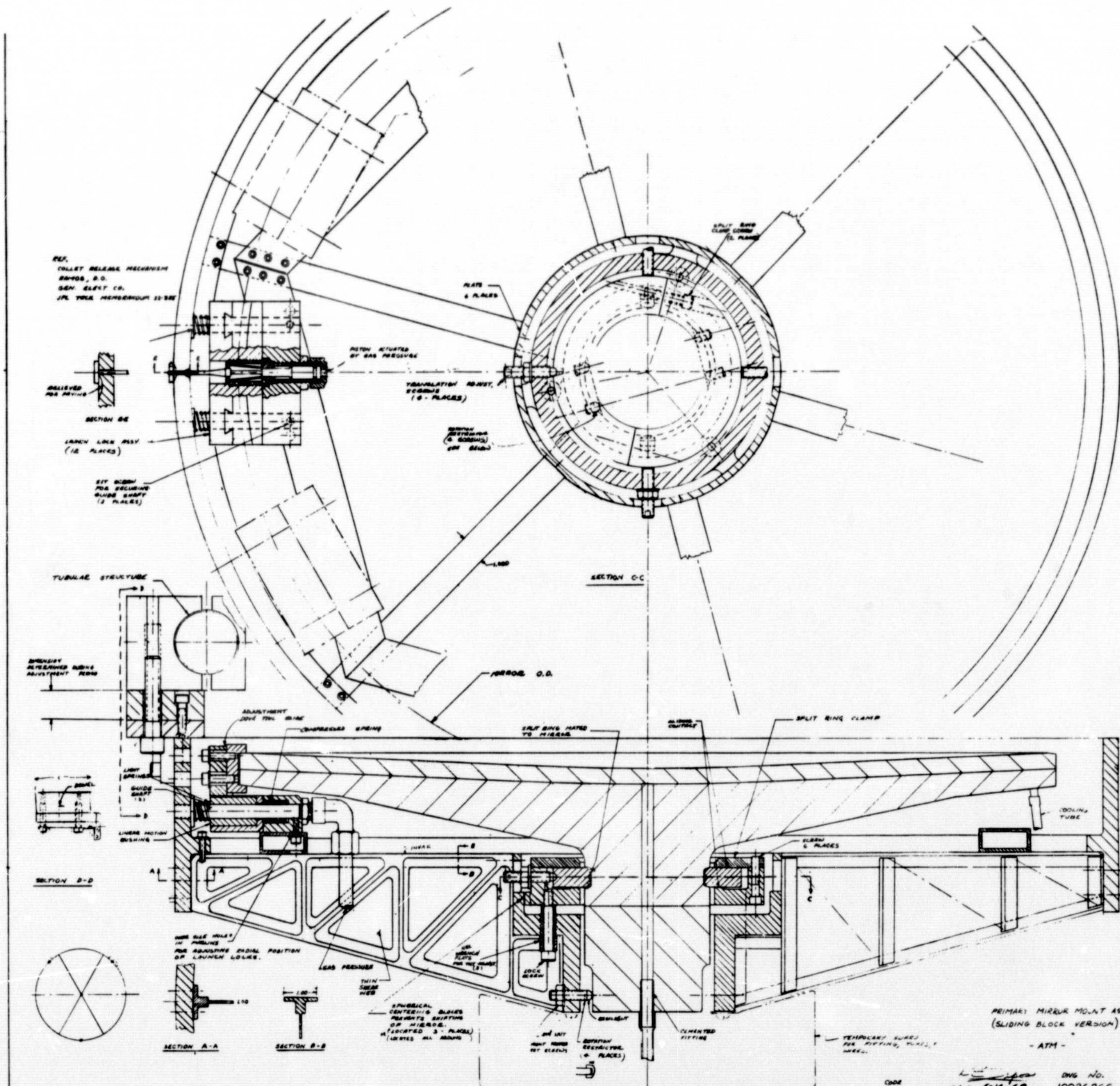


Fig. 4. Primary mirror assembly, sliding block version

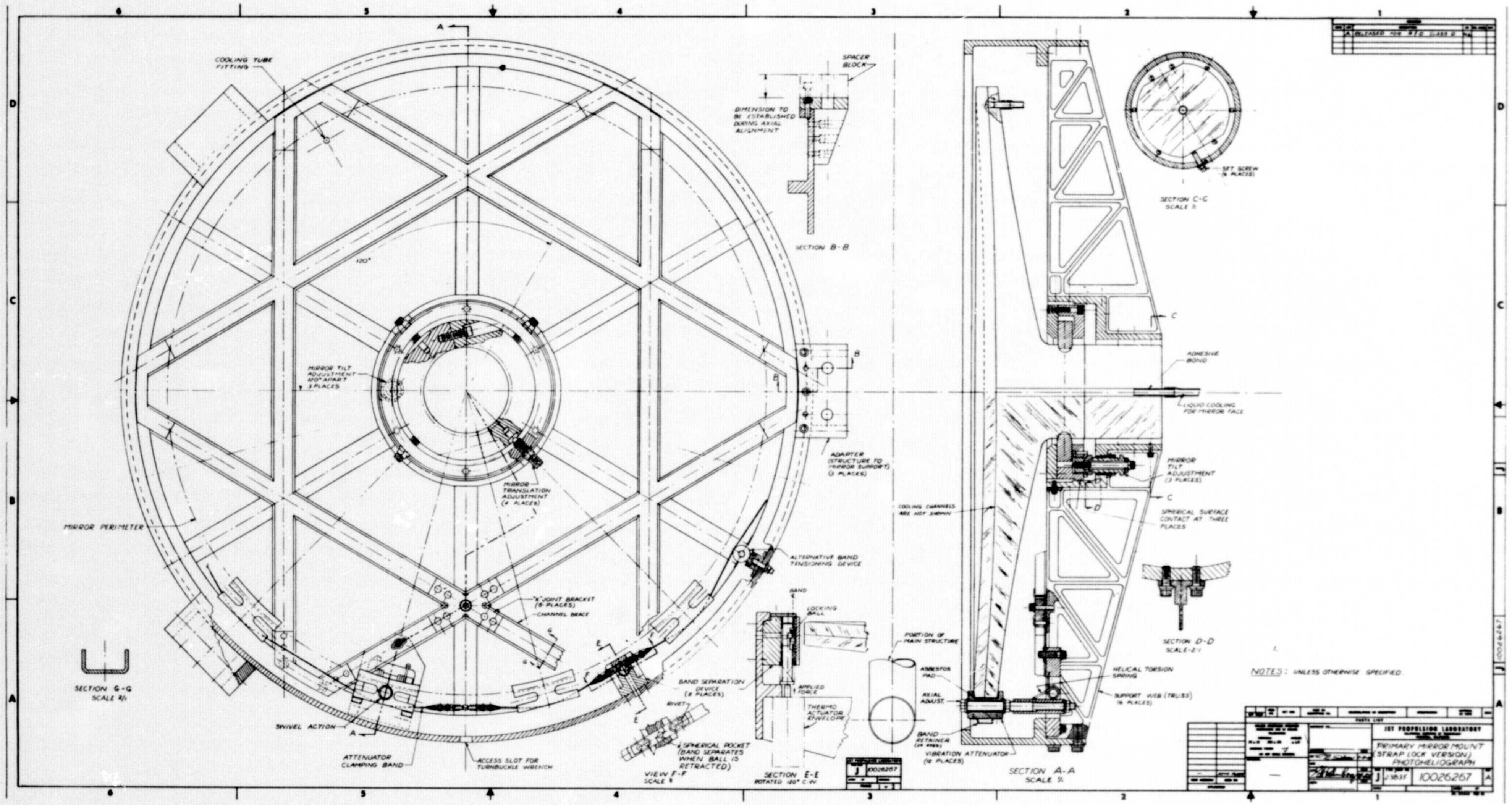


Fig. 5. Primary mirror assembly, strap lock version

the dust contamination sleeve, the thermal control fluid piping, and the doors in the canister provided by the ATM. Also, the possibility of astronaut EVA for adjustments or film change or repairs might be added. The electrical interface includes raw power to the photoheliograph plus the control and signal lines to and from the photoheliograph and the astronaut control console in the LM. The optical interface consists of (1) the pointing of the telescope and (2) the alignment of the telescope with the fine sun sensor. The optical input is then converted to electrical energy and becomes part of the electrical interface. The optical requirements specifications have dictated certain requirements on the structure for initial alignment and in-space realignment.

ALIGNMENT MECHANISM

Two methods of approach to an alignment mechanism are possible: (1) everything bolted or welded in place so that it will not shift, but would result in a tremendous weight penalty, or (2) the logical approach, which is to make everything that might move, adjustable.

As long as adjustments are being made, the range should be large enough to compensate for fabrication tolerances. Initially, there are optical tolerances in the primary mirror, namely, the location and angle of the optical axis and the focal length. This immediately requires five degrees of freedom in the mounting cell of the primary mirror - that is, five rather than six degrees of freedom because as the mirror is circumferentially symmetrical, roll is not a factor. The exact same tolerances plus roll apply to the concave secondary mirror, and the same alignment adjustments are built into the secondary mirror mount. The roll, or sixth degree of freedom is important because at the center of the secondary is the small alignment mirror, which receives a beam at three degrees off the optical axis. The in-space realignment mechanism in the secondary assembly will take care of all necessary realignment of the telescope due to small permanent shifts in the structure such as slippages of truss joints and so on, but not catastrophic changes. Catastrophic changes would be ones that require EVA to manually realign a normally fixed item such as a secondary flat, or to put the camera back on its track, or to repair the mount, etc. A telescope structure cannot be built to these weight limitations and only elastically deform due to the given launch loads. There may be some shift. It is not a completely homogeneous structure; there are bolted and riveted joints.

During initial assembly, each optical component will have to be adjusted as far as its alignment is concerned. This is due to the inherent manufacturing tolerances of the mirror themselves, of the mounts, of the structure, and so on. The adjustments on the primary mirror are in the clamps around the central hub, which can tilt the mirror in pitch-and-yaw and shift it laterally Z and Y (spacecraft coordinates, see Fig. 2). After that is done, the launch locks, which are located around the outside circumference of the mirror, are individually adjusted so that they fit properly. The coarse adjustment of the axial or X-position (again, spacecraft coordinates), which is the primary to secondary spacing and may vary plus or minus 1-inch from nominal, is done by spacer blocks between the primary mirror cell and the first ring of the housing structure. There are three sets of these because there are three bolt points between cell and housing. The fine X adjustment will be done later, in space, by the mechanism that moves the secondary assembly. We can allow this because the total motion of the secondary, as far as is optically permitted, is plus or minus 0.040 inch. The total X-direction travel of the secondary that has been built-in to take care of all possible contingencies, is plus or minus 1/8 inch.

Within the secondary assembly we have the same tilt and Z-Y position adjustments as for the primary mirror and also the secondary cell can be moved in the X-direction relative to the central tube. The reason for this Z motion capability within the secondary is to take care of the tolerance in the focal length in the secondary mirror. Thus, there are three X-direction adjustments; first there are the primary cell-housing spacers which is a coarse adjustment of primary to secondary distance, second is a coarse adjustment of the secondary mirror, which compensates for the secondary focal length, that is, the distance from the field stop in the heat-stop mirror to the secondary mirror, and the third is the fine adjustment of the entire secondary assembly, which can be done repeatedly, on the ground and again in space.

Each of the three diagonal flats in the secondary assembly (see Fig. 6) namely, the heat-stop, the first diagonal flat on the inside of the secondary assembly, and the second flat up behind the corner of the light tube, has in its cell a three-point suspension that is adjustable to take care of small tilt requirements. This is also an initial adjustment, on the ground, during assembly. The final assembly adjustment is in the camera cluster. Each component can

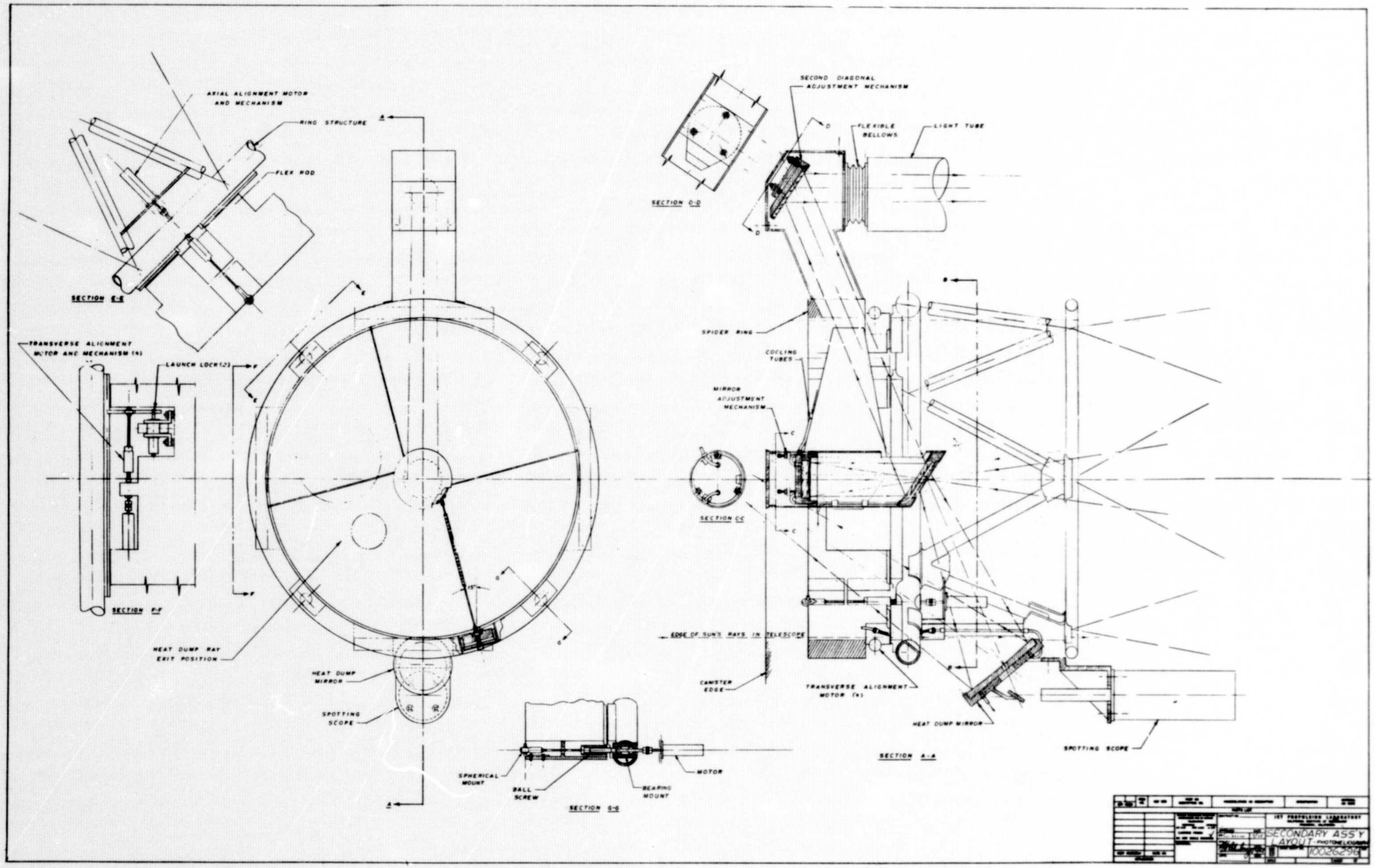


Fig. 6. Secondary assembly layout

be shimmed and the entire movable track can be adjusted, up and down and laterally. This is in order to get the beam of light centered on the camera frames when everything else is in neutral position. The first adjustment for the camera rack is to get the final field stop centered on the beam. After that each component can be centered on the beam. In progression, these include the beam splitters, the filters, the cameras, and the monitoring vidicons.

The tightest tolerances that we have after the primary-secondary distance is the location of the alignment sensor relative to the optical center of the primary mirror. This is our reference for in-space realignment. For that reason the alignment sensor is mounted directly to the primary mirror cell to minimize the mechanical path length between the optical axis and the alignment sensor. Zero shift between those two is desirable. The allowable is very small, on the order of ± 0.001 in. between the optical center of the primary mirror and the center point of the rotating knife edge in the sensor.

There are other, non-critical adjustments, such as the heat-dump mirror, the small diagonal mirror in front of the spotting scope and the spotting scope itself. But these adjustments can be by standard shim or slotted bolt-hole construction. Undetermined at this time is what alignment adjustments are necessary for the telescope as a whole, relative to the ATM spar, in order to bring us into alignment with the fine sun sensor or the ATM spotting scope. These may not be at all necessary because differences in pointing can be calibrated during final alignment tests. The active alignment (and realignment) control is mainly the motion of the secondary mirror assembly and in conjunction with the alignment sensor and can be can be used during in-flight, photographic operation. It is not a one-time effort like the ground alignments during assembly.

PRIMARY MIRROR

REQUIREMENTS

In evolving a design for the primary mirror, various requirements sometimes conflicting, had to be considered. Each had to be satisfied, at least in part, to the extent that no optical or operational constraint was compromised. The resulting configuration is somewhat unorthodox, but only in superficial appearance. Structurally, and fabrication-wise, the design is sound. The final configuration (Fig. 7) of a thin, radially tapered, solid structure with internal active cooling passages and a stabilizing hub at the rear represents the best compromise and, on paper, satisfies each of the requirements.

From the various pertinent documents, in-house analyses, and discussions with cognizant personnel at MSFC, Martin-Marrietta, and Bendix, the following mechanical requirements for the primary mirror were obtained:

(1) Material amenable to the usual grinding and polishing techniques for high quality optics

(2) Low expansion coefficient, or high thermal conductivity, or both

(3) Material to be homogeneous such that any thermal or load deflection will be uniform around a circumference within the optical path difference (OPD) tolerances

(4) All dimensions to have circumferential symmetry

(5) Launch loads (acceleration, vibration and acoustics) to be those of Appendix A (worse case at the spar-unattenuated), MSFC Spec. 50M 02408, "Environmental Design and Test Criteria for ATM Components" January 31, 1967

(6) Vibration and shock levels in operation assumed zero or of such a low level as to have no inelastic effect on unlocked components

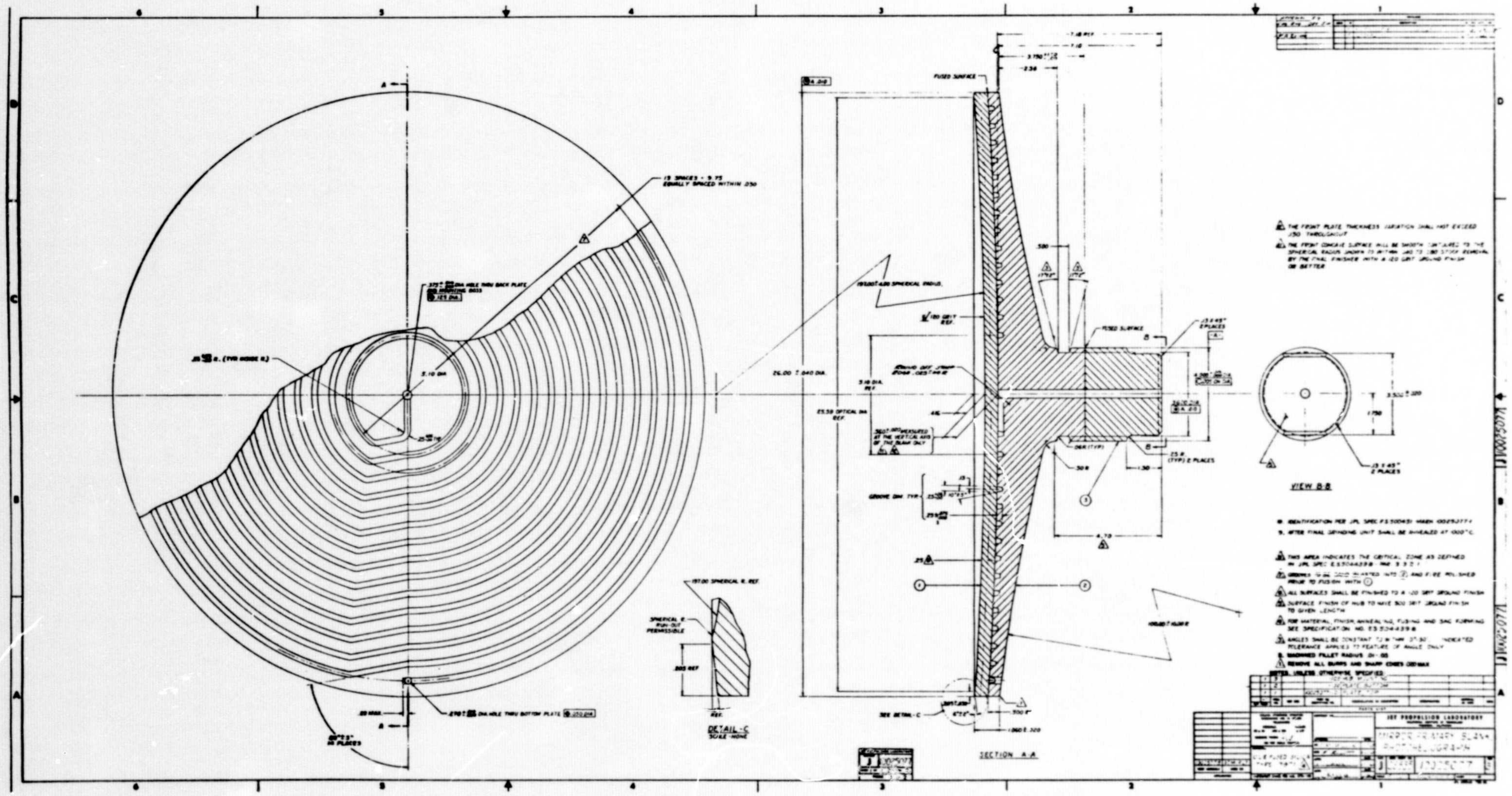


Fig. 7. Primary mirror blank

(7) Active thermal control (liquid cooling) of all critical optical components. The criteria are to be whether or not the surface is in the primary optical path, the expected surface temperature without active cooling, and the presence of adjacent, thermally conductive structure

(8) Weight to be reasonable, of the order of 10 percent of the entire assembly, consideration to be given to adequate support by a mounting cell of practical proportions

(9) One-g deflection (for pre-launch testing) to be either negligible optically, or able to be calculated with certainty. Deflections greater than the OPD tolerance to be second order parabolic radially

(10) For the Gregorian arrangement, with uniform thermal input over the face of the primary, the liquid cooling must be at a constant distance behind the face and uniformly distributed over the area

(11) For minimum surface temperature rise (and hence, minimum thermal distortion), the distance between the front surface and the cooling passages should also be a minimum, with due consideration to problems of fabrication and figuring

(12) Remotely controlled, single-shot locks or clamps to be provided to take the calculated launch loads. (The practical locations are around the outside circumference - see later discussion)

(13) The operational holding arrangement to be fixed and undisturbed by the launch loads. Maintaining the location and alignment of the primary mirror relative to the cell is absolutely required if the alignment sensor is to be relied upon for adjusting the secondary assembly in space. (The practical location for this is at the center - see later discussion)

ASSEMBLY (Figs. 4, and 5)

The primary mirror assembly includes the primary mirror proper, the mounting structure with its initial alignment adjustments, the cell that supports the mounting structure, the launch locks, and a bracket for mounting the alignment sensor. The configuration and the performance requirements on the primary mirror are described elsewhere in this report; however, the cell and the mounting structure have a few additional constraints and requirements. First, the mirror must be held securely during operation at the required position and orientation. This holding system should be lightly loaded by the launch environment in order to minimize any chances of shift in the initial alignment. Secondly, a launch lock systems must be provided which can be positioned prior to launch and unlocked, on a one-shot basis, just prior to operation. These launch locks will consist of a series of shoes around the outer circumference of the primary mirror, located at equal intervals of 30 degrees. Each spans about 5 degrees of the mirror circumference. Two systems are presently in the process of being designed: (1) each shoe is individually unlocked by a thermal actuator similar to the ones used in the secondary assembly (See Fig. 4) -- a simpler but less reliable system, and (2) pivoted shoes, clamped into position by a circumferential band which is separated at two points, diametrically opposite, giving redundancy in the unlocking and high-reliability (See Fig. 5). In the second system, unlocking is also effected by thermal actuators which remove pins, or locking balls in the overlapping ends of the strap.

The outside launch locks will take the majority of the longitudinal acceleration and will restrain the mirror from any tilt due to lateral or torsional vibration. They will also prevent the outside ends of the mirror from flapping up and down relative to the center due to longitudinal vibration. Initial stress analysis, to size the bolts and shoes themselves have been done based on the assumed 50-g - equivalent static load (See Appendix C). The lock and mounting assembly has been examined for all principal vibration modes, rigid body, oil can, and lateral. If the rigidity of the hub support and rim support can be estimated, the lowest rigid body frequency for the mirror can be calculated as follows.

$$\omega^2 = \frac{K_r R_r + K_n R_n}{m} 2\pi \text{ (radians/sec)}^2$$

where,

R_r = Mirror Radius (in.)

R_n = Hub Radius (in.)

K_r = Rim Support Stiffness (lbs./in.^{2})

K_n = Hub Support Stiffness (lbs./in.^{2})

m = Mirror Mass (slugs)

The center of the mirror is not free, but is restrained in the axial direction by the operational mount. Each outside clamp shares an equal mass of mirror. There will be some elastic motion of the mounting structure, as the lowest stiffness will be the center attachment. Moderate vibration of the mirror as a rigid body would not be objectionable, providing all members stay within their elastic limits. The amplitude can be held down to a reasonable limit by providing absorption pads or coatings or by selecting structural materials for high internal damping. Thus, the first two requirements are: (1) a secure stable operational mount, and (2) launch locks to prevent fracture. The third requirement is that the mirror should not deflect during vibrations, and that, if it moves, it moves as a rigid body. This means that the outside clamp system should have a stiffness comparable to the center support, because if they are rigid, the load will be transferred from the center to the outside edge during each vibration cycle. Either of two systems shown can be made to work, but more analysis is needed before we detail design the components.

The support structure located behind the mirror consists of a series of six radial trusses running between the outer cell ring and a center tube surrounding the hub of the mirror and holding the operational mount mechanism. The preferred design of these trusses is to have them machined out of aluminum sheet stock. This eliminates web fasteners and corner joints for the stiffeners. Each truss will be bolted to the rings of the inner and outer end. The trusses have also been designed to carry the majority of the bending moment at the inner edge because this arrangement improves the stiffness without a weight penalty. Adequate clearance is provided for the cooling piping to and from the mirror, for adjusting the launch lock blocks, and for adjusting the center operational holding assembly.

This center assembly has several features of interest: (1) a ring (metallic) is lapped into a groove at the base of the primary mirror hub. This ring is held by a split shoe circumscribing it. The ring itself is split in two or three pieces so that it can be cinched up tight into the groove after the lapping. The shoe is attached to the support tube by three axial bolts with ball joints. These bolts can adjust the mirror in the X-direction a small amount and can tilt it in pitch-and-yaw for initial alignment of the primary mirror optical axis. The lateral position of the ring is controlled by four over-sized set screws. They provide the Z and Y adjustment. The shoe is fixed in the Z and Y direction and has as its outer edge a section of a large spherical ball which rides against the tube. Z and Y motion of the mirror is controlled solely by the inner ring being moved relative to the shoe. At this point, the holding of the Z and Y position is quite rigid, but the holding in tilt is not because of the short wheel-base of the clamp ring. Therefore, additional set screws have been provided at the very rear end of the hub. There are two sets of screws: first are four which are mainly holding screws; and then there are four additional ones that press against flats at this back end, which hold the mirror from rolling around the longitudinal X-axis. All of these screws are accessible after the primary mirror and cell have been assembled to the housing. This allows for adjustments during initial assembly and readjustments, if necessary, on assembly of the telescope to the spacecraft.

A fourth constraint, on the design of the launch lock system in particular, was that the release mechanisms could not be explosive types nor could they be hydraulically actuated, because in either case there was a danger of leakage of a volatile working fluid which could contaminate the optical surfaces. Also, explosive squibs are not allowed on man-rated systems. The thermal actuators are totally sealed, are not explosive, and their reliability, from past experiences, has been extremely high. They can also be tested repeatedly prior to launch.

As designed, the overall length from the rear of the primary mirror in its nominal position to the sunshade at the end of the secondary mirror assembly is exactly 120 inches. This was the limit imposed by the spar dimensions of the ATM. Marshall, Bendix, and Martin, have given verbal permission for using an additional three inches beyond the spar at the LM end of the ATM. This will be used for the cooling fluid fitting at the center of the primary mirror hub. After assembly, a guard will be placed over the hub to prevent any damage. As presently envisioned for use with the ATM, if any of the launch locks stick or fail to actuate, there are provisions for emergency unlocking, either by manually reactivating the launch lock or by prying the shoe unlocked through an access hole. This feature exists at both the primary and secondary assemblies.

SECONDARY MIRROR ASSEMBLY (Figs. 6 and 8)

Basically, this assembly consists of the secondary mirror and mount, the two diagonal flats, the heat-stop mirror, the secondary mounting spider and the outside support ring. This assembly is a light-weight rigid structure because it is controlled as a rigid body for realignment. Connecting the secondary assembly and the sun end of the housing structure are, first of all, four launch locks and then eight motor-gear-train pushrod assemblies. Four of these latter assemblies are for X-direction adjustment plus pitch and yaw tilt. The other four are for Z and Y motion, plus roll. During launch the X direction motors will be retracted and the secondary will be tight against the end of the housing. There will be little or no load on any of the alignment pushrods. The launch locks will pull the secondary assembly tight against the end ring of the housing. The Z and Y restraint is by a serrated lip around the housing, that prevents Z and Y motion and roll of the secondary assembly relative to the housing. The launch locks are released by thermal actuators. These are cylinders with flexible end bellows. They are filled with a high-expansion material plus a small heater winding. When electric power is run through them the material expands and pushes or pulls a rod. The rod then comes out of the launch lock hole and catches on a ratchet which holds it in the unlocked position. It is strictly a one-time unlocking. This is done after the telescope is in orbit, finished with its docking, and ready to operate, because relock for any subsequent maneuvering is not possible.

After the secondary is unlocked, the X-axis motors are run until the secondary ring is approximately 1/8 inch away from the end of the housing. This is its center position for subsequent in-space realignment. The lateral direction is controlled by four similar assemblies which are arranged circumferentially around the secondary ring, that is, for the Z and Y direction plus roll. They push against brackets that are attached to the end ring of the housing. By operating these is pairs Z and Y motion can be obtained in any direction. By operating all four together, in the same direction, roll can be obtained,

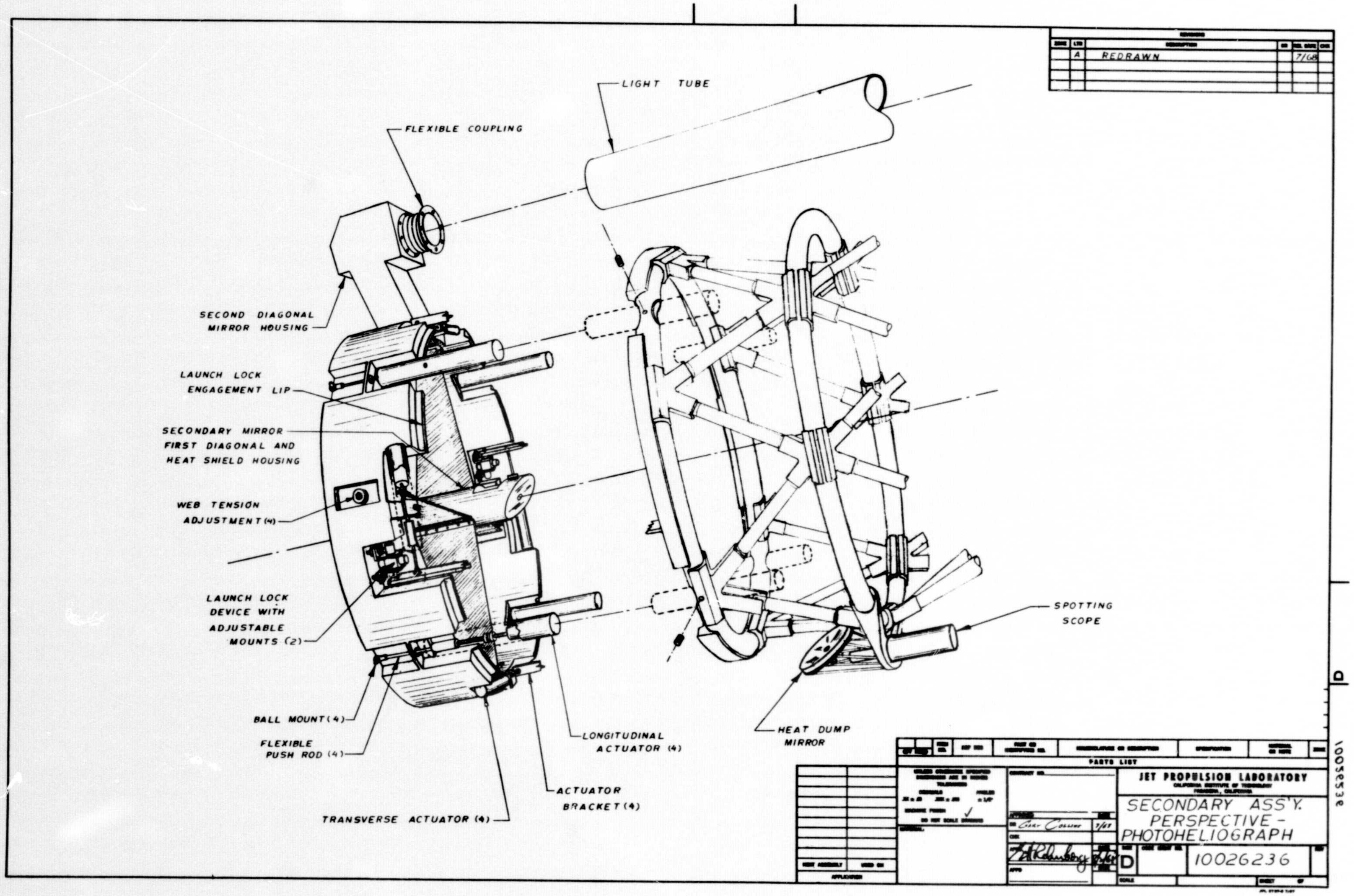


Fig. 8. Secondary assembly perspective

which may be useful in repositioning the final image at the cameras after realignment of the secondary assembly has been accomplished. The Z axis pushrod assemblies have a ball joint at the ends which, at the request of the optics people, has been located in the plane of the secondary mirror surface so that all tilting is done around the center of the secondary mirror. The lateral pushrod assemblies also are terminated in a ball joint, but their location is not critical to the assembly, and they have been located for convenience to the mechanical package. These motors assemblies could have been groups of three or four. Three would give all the control needed, except for roll, because lateral stability would be lacking with a circumferential arrangement. The four X-direction motors provide an additional bonus. Because its impossible to run them all exactly the same amount, the system is always locked. There is no backlash or slop for any amount of adjustment. A strain is developed, but the pushrod can take some 20,000 psi, and the motors are capable of only developing something in the order of 2,000 psi. The motor runs through a gear train. This actuates a threaded rod which rotates inside a ball nut. The nut is attached to the pushrod and is restrained to move only axially. The pushrods are approximately 1/4 inch in diameter by 4 inches long. They can flex sideways 1/8 inch without exceeding 2000 psi. Once in orbit, there are no static loads on this assembly, so the size has been more controlled for fabrication convenience than by any strength requirements. Also, the constant threat of a small vibration level during operation means that the pushrod should be of a size convenient for applying damping material or sufficiently stiff to prevent objectionably large amplitudes.

PHOTOHELIOGRAPH HOUSING STRUCTURE (Figs. 3, 9, and 10)

In the initial design, the housing for the photoheliograph was a cylindrical aluminum honeycomb structure. The inner and outer skins were 0.020-inch aluminum sheet and the center was either aluminum or non-metallic honeycomb or foam. The housing extended from the primary cell to the secondary assembly. At the secondary end was a terminating ring, holding the realignment mechanisms. Mounting to the ATM spar was to be at the primary cell and at this terminating ring. A three-point mounting system similar to the present design was envisioned.

The advantages of a solid cylindrical housing are that it provides a maximum of strength and rigidity for a given weight, or conversely for given set of loads a minimum weight. Attachments to the housing for various high load points, such as the mounting of accessories and the mirror assemblies, is easily accomplished by reinforcement plates or gussets. Access for mirror adjustment can be by means of small doors. Thermal insulation between the optical components and the surrounding ATM structure is automatically provided by the housing.

The disadvantages of this type housing are not immediately apparent. However, analysis has shown that during launch, the housing acts as a half-wave organ pipe with the primary mirror acting as the end closure. This pipe is resonant at various frequencies between 35 and 200 cps, from sea level to 15 km, which is in the region of maximum acoustical energy. Further analysis indicated that the primary mirror support system within the given weight limits could conceivably have a stiffness such that the primary mirror would resonate as a rigid body also in the region of 200 cps. Together these created a very unsatisfactory situation.

Another difficulty with an aluminum housing is the high thermal expansion coefficient. It is expected that the housing temperature could vary from below 70°F to above 75°F during normal operation. This is because the end cover would be open during the entire orbit, half of which would be sunlight and half in the shadow of earth. A 5° to 7°F change in temperature would change the length of the housing by .015 inch. This is not beyond the capability of the realignment mechanism as to magnitude but it is in regard to the rapidity in which it occurs. Refocusing the camera could compensate for a part, but not all. To overcome this, 3 spacer rods made of low-expansion, super-invar alloy were located around the housing. As the launch locks are released, the secondary comes to rest on the ends of the rods. The housing is then free to expand or contract within these rods; and thus primary to secondary mirrors spacing is maintained. However, if, during operation, the telescope should point off from the sun by more than 1 degree, sunlight will strike one side of the housing. In this case, there will be a differential expansion between the opposite sides of the housing, and the tube will bend laterally. The lateral movement of one end relative to the other could be as much as 1 1/2 inches, which definitely beyond the correction capabilities of the realignment mechanism. To date, there is no assurance that the telescope pointing will be maintained within the required plus or minus 1/2 degree throughout the entire orbit. It seems reasonable to expect greater deviation when one considers the Fine Sun Sensor is the basis on which the pointing control is operated.

The truss housing now designed eliminates these problems of acoustics and thermal expansion without undue penalty in weight. This is accomplished by making the truss structure of thin-wall invar tubing. The procedure has been used before here at JPL. Fig. 3 shows the structure. The arrangement falls within the size boundary of the telescope quadrant without obscuring any of the primary mirror. The mounting for the spar may now be directly to the housing at the ends with the primary and secondary subassemblies attaching directly to the housing. The camera cluster and light tube, which are in the adjacent quadrant also attach directly to the housing by means of clearance holes through the spar.

Stress analysis has been made on this structure under the theorized 50 g equivalent static load (See Appendix C and D), and the tube sizes have been tentatively determined. Besides eliminating previous problems, this type of structure provides less complexity and considerable increase in strength for supporting the optical assemblies during launch. For thermal insulation, a blanket of aluminized mylar (so called "super insulation") will be wrapped around the housing. This will have an added advantage of providing considerable vibration damping to the individual truss members. Reinforcement plates are added where necessary to support accessory equipment such as the secondary realignment mechanisms, the spotting scope, the head dump mirror, and the mounting brackets to the light tube and to the heat radiator.

The mounting to the spar will be by a three-point assembly as shown in Fig. 3 or in Fig. 9 and 10. This latter system is similar to that used by Ball Bros. Research Corp. on other ATM experiment designs. It includes a single ball at the secondary end, which takes loads in all three directions. At the primary end are 2 trusses which take lateral loads as well as restrain the telescope from rotation about any axis. Side loads at the primary end are taken by a third member inclined to the other two. All of these members have ball joints to prevent the development of any bending moments within the members themselves. Mountings of this type are also useful in creating a path of high thermal resistance between the telescope and the spar. Small cross-sections and low-conductivity material, such as titanium tubing can be used and still have adequate strength within the space limitations. Various versions of the three-point support are possible, but in any form, it is desirable to prevent the loading of the telescope due to any distortions of the spar or frame work to which the telescope is mounted, either due to launch loads or to temperature changes within the structure.

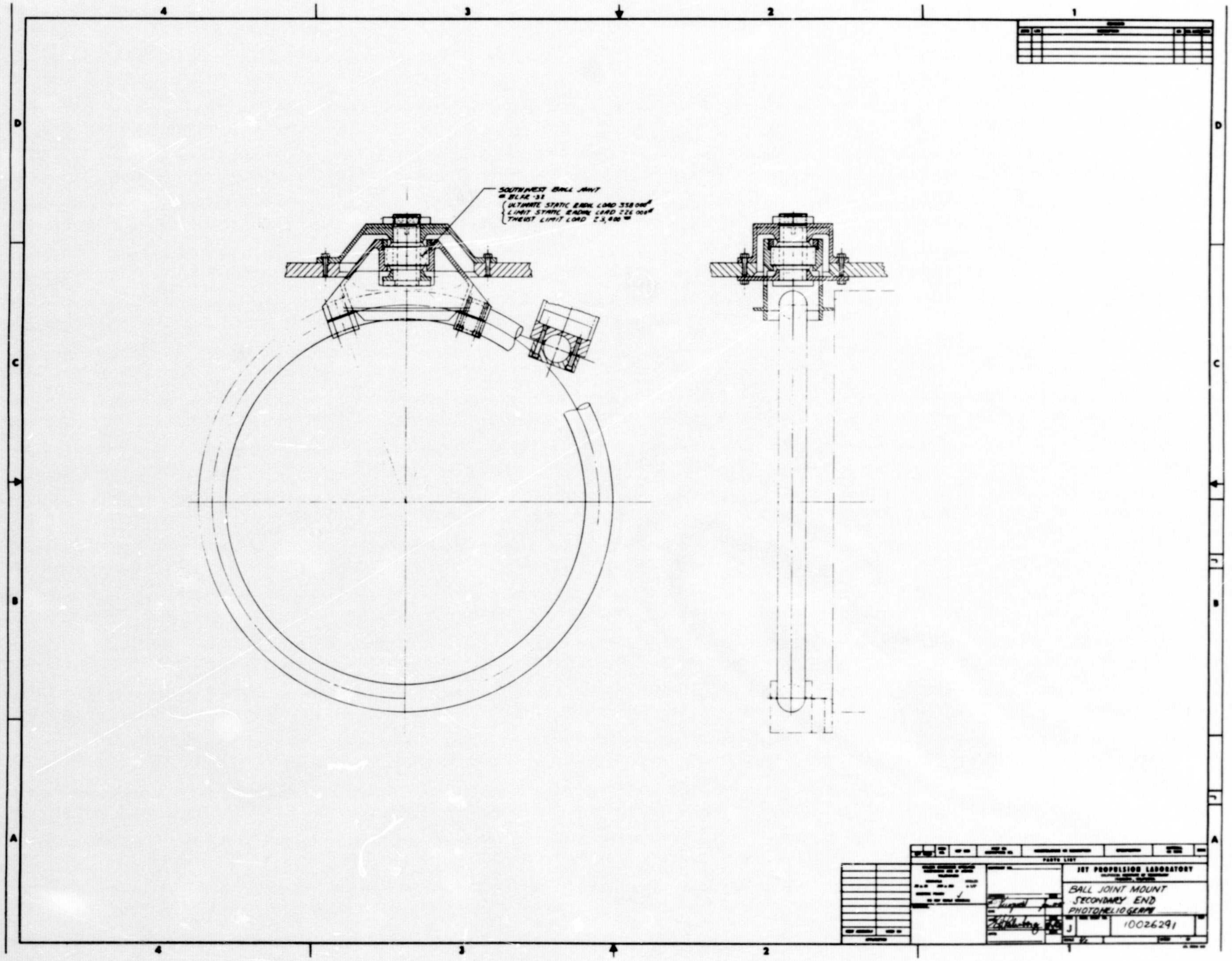


Fig. 9. Ball joint mount, secondary end

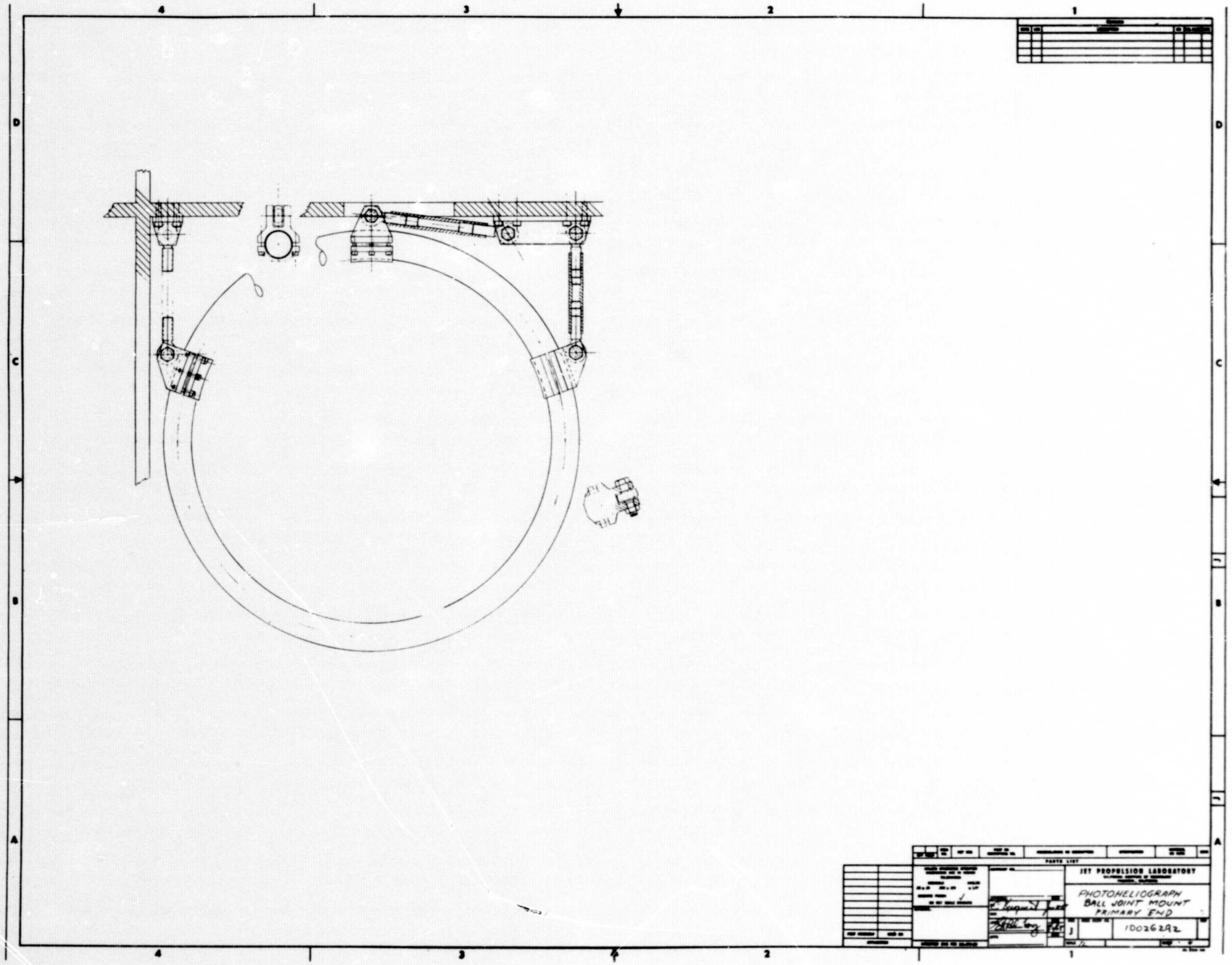


Fig. 10. **Ball joint mount,** primary end

THERMAL CONTROL PROVISIONS (Figs. 1, 11, and 12)

In the secondary assembly each mirror absorbs some solar energy. If there were no cooling provisions, the surface temperatures could rise to the point where either the mirrors would distort or the surface coating material could be lost. The mirror that receives the highest heat load in watts/cm^2 is the heat-stop mirror at the primary focal point. The entire solar energy from the 65 cm. primary is concentrated into an approximate 2.5 cm diameter image. This represents 400 watts, approximately 10 of which go through the little hole in the center, about 20 watts are absorbed even though the mirror is silvered rather than aluminized for its higher reflectivity, and the balance of that energy is reflected over into a concave heat-dump mirror located at the housing side wall. Again approximately 20 watts is absorbed, and the balance about 350 watts, is dumped diagonally out through the front opening into space.

Of the 10 watts that pass through the primary field-stop hole, about 1 watt is abosrbed at the secondary mirror and at each of the diagonal flats. The secondary mirror and the first diagonal are provided with active cooling. Part of the main liquid cooling system for the telescope is bypassed in series or parallel with the primary mirror. Tubing is run along the spiders, one to conduct the liquid into the secondary assembly and another to conduct it back out. The fluid comes in first to the secondary mirror and then passes down the secondary tube to the first diagonal flat. Between the first diagonal flat and the field-stop mirror is a plenam chamber. In other words, we use the cooling fluid itself as the heat barrier between the heat-stop mirror, which gets very hot, and the first diagonal flat which must be protected because the two are very close together, and it was not practical to use a tubing grid for conducting the fluid between the two. From there, the fluid passes back out of the secondary assembly and over to the heat dump mirror, which has a "token" spiral of tubing on its back just to keep the temperature from running away.

The second diagonal flat is isolated from the rest of the telescope and has a large mass of metal around it in the form of mounting and light tubes. It is located in the next quadrant, which has a direct view of the ATM cold wall in the canister; so it was felt that conduction and radiation would be adequate, and that no liquid cooling was necessary. This leaves about 6 1/2 watts of energy passing down the light tube towards the camera cluster.

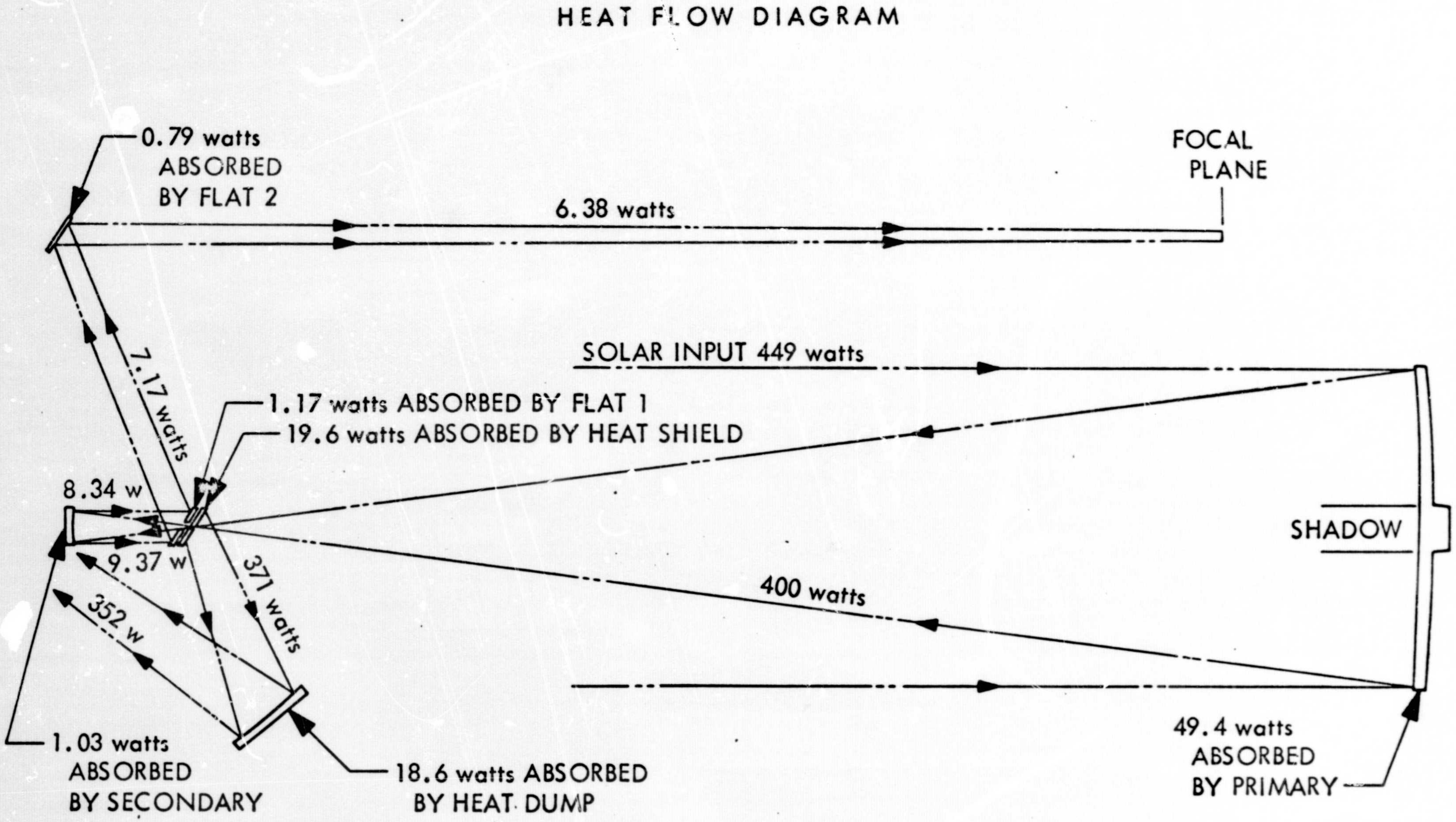


Fig. 11. Heat flow diagram

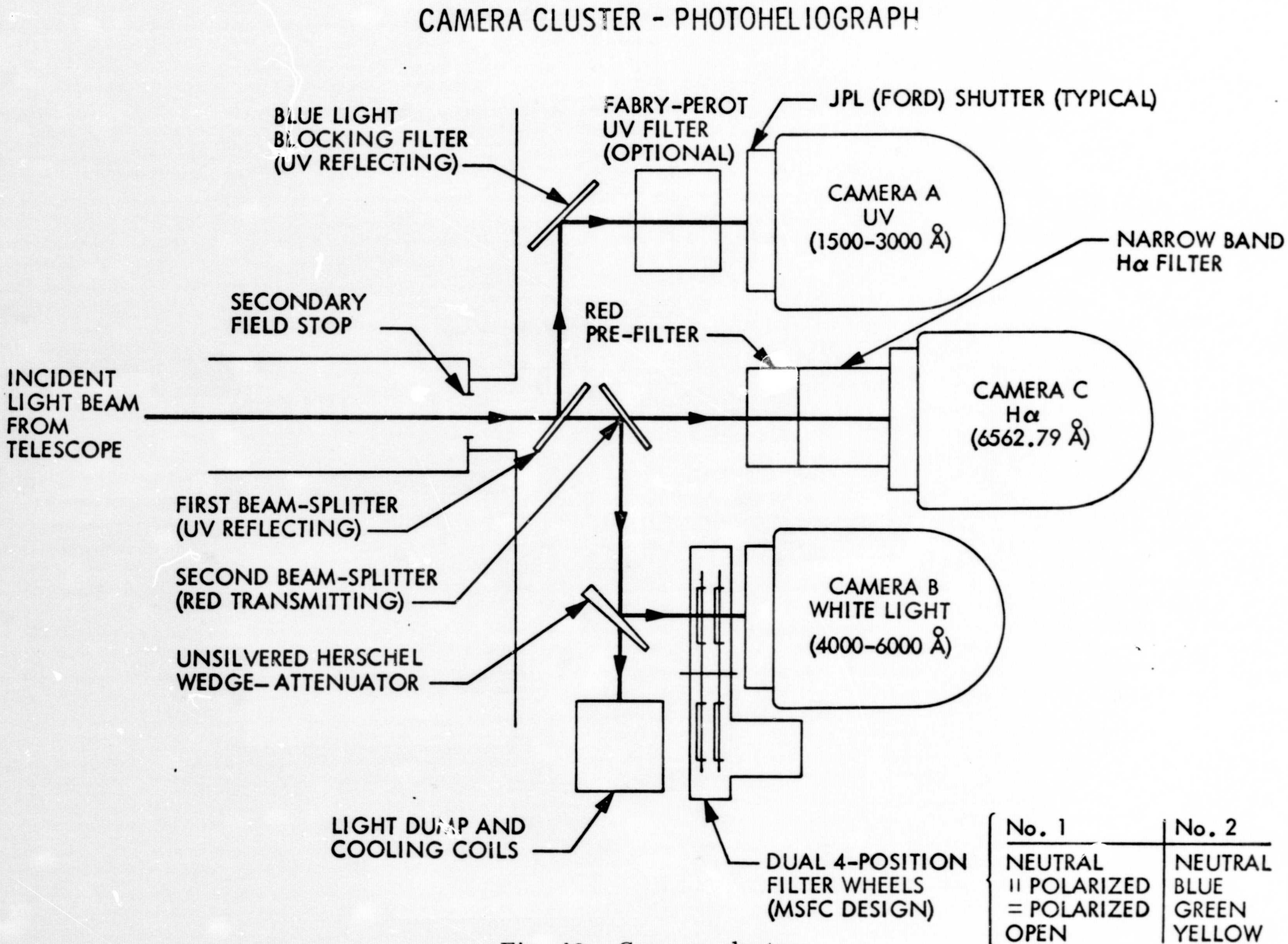
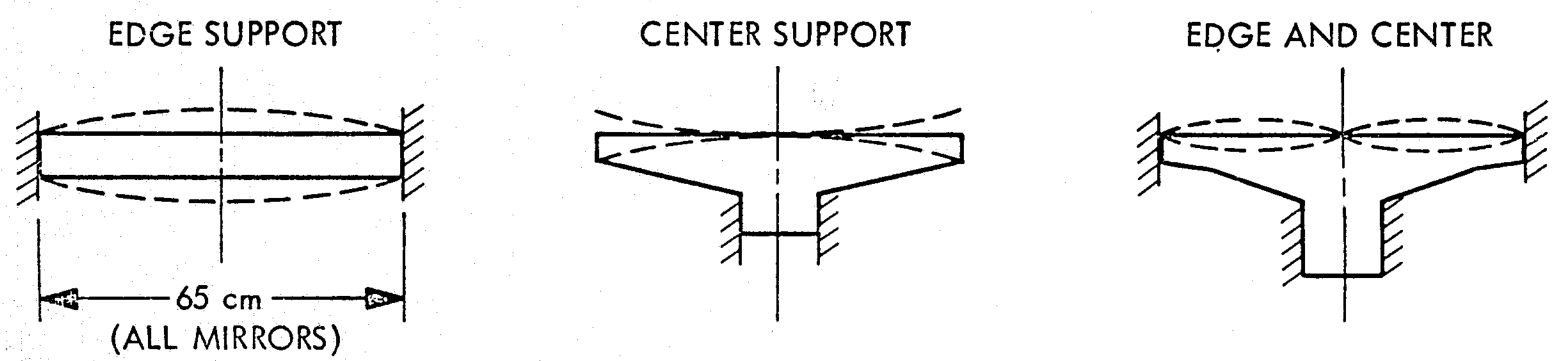


Fig. 12. Camera cluster

750-13

PRIMARY MIRROR
NATURAL FREQUENCIES OF QUARTZ MIRRORS

	DESCRIPTION	MOUNTING	THICKNESS, in.	WEIGHT, lb	FREQUENCY, cps
1.	CONSTANT THICKNESS	EDGE	1	65	400
2.	CONSTANT THICKNESS	CENTER	1	65	250
3.	CONSTANT THICKNESS	FREE	1	65	350
4.	CONSTANT THICKNESS	EDGE	3	196	1200
5.	TAPERED, UNIFORM, WITH SHORT HUB	EDGE	1 TO 3	74	760
6.	TAPERED, UNIFORM, WITH SHORT HUB	CENTER	1 TO 3	74	510
7.	TAPERED, UNIFORM, NO CENTER HUB	EDGE	1-1/2 TO 4	101	1080
8.	TAPERED, DOUBLE, WITH LONG HUB	CENTER	1 TO 4	84	640
9.	TAPERED, DOUBLE, WITH LONG HUB	EDGE AND CENTER	1 TO 4	84	1780



ASSUMPTIONS:

ALL MIRRORS 65 cm DIA
ALL MIRRORS OF QUARTZ
OUTER EDGES SIMPLY SUPPORTED, CENTERS CLAMPED

Fig. 13. Natural frequencies of quartz mirrors

After the action of the beam-split and filters, about 5 watts of this are still left over as excess heat. This comes off the second beam splitter along with the white light beam and passes through a Herschell wedge, which peels off just a small amount needed by the white light camera. The energy that passes through the Herschell goes into a light horn, which is a totally absorbing dump. This may or may not be provided with liquid cooling coils. The provisions are in the design, but this horn has a clear view of the ATM cold-wall and radiation fins may be sufficient. So far, we have made no provisions for active cooling of any of the cameras or filters. The total power consumed by these is, in the case of vidicons, in the order of 2 watts apiece; and they have a large surface area. We feel that radiation cooling should be sufficient. Film cameras may use, intermittently, 25 watts per motor. There is a motor for film advance and one for shutter control in each camera. Also, in the Hα camera, if a Lyot type filter is used, there may be an additional 35 watts for its thermal control system which will have to be dumped somehow. If a Fabry-Perot type is used, then the wattage drops to about 2 and can be radiated directly to the cold-wall.

APPENDIX A

PRIMARY MIRROR VIBRATION

APPENDIX A

PRIMARY MIRROR VIBRATION

Dr. C. Babcock
Professor of Applied Mechanics, California Institute of Technology

I. SUMMARY

The following is a summary of the calculations made to determine the lowest natural frequency of the mirror supported in various manners. The details may be found in the Analysis Method Section.

(a) Frequencies (Uniform Thickness)

All of the frequencies calculated can be written as follows

$$f = K \sqrt{\frac{E}{\rho}} \frac{t}{R^2}$$

For the mirror ($E = 13.4 \times 10^6$ psi, $\rho = .09$ lb/in^3)

$$\sqrt{\frac{E}{\rho}} = 240,000 \text{ in/sec}$$

For a uniform Mirror the following values of K have been found (use $\nu = 1/3$)

SUPPORT

Inside (r = 0)	Outside (r = R)	K
None	Simple Support	.277
None	Clamped	.500
Clamped	None	.181
Clamped	Simple Support	1.194

(b) Non-Uniform Thickness

A calculation to determine the effect of the non-uniform thickness was carried out. It was found that the error in frequency was less than 14 percent if an average thickness was used

$$\left(t_a = \frac{\text{Base Thickness + Rim Thickness}}{2}\right)$$

If thickness giving the same volume is used the error is less than 3 percent for $\alpha < 1/2$ where

$$t_{Rim} = t_{Base} (1-\alpha)$$

(c) Analysis Accuracy

In order to determine the accuracy of the analysis the results were checked against an exact calculation. For a clamped uniform plate

$$f \text{ exact} = .494 \sqrt{\frac{E}{\rho}} \frac{t}{R^2}$$

$$f \text{ approx} = .500 \sqrt{\frac{E}{\rho}} \frac{t}{R^2}$$

The error in this case is less than 2 percent

(d) Effect of Hub

The mass of the hub can be accounted for by adding it into the kinetic energy term in the analysis. This gives the following result for the simply supported plate

$$\frac{f \text{ (with hub)}}{f \text{ (no hub)}} = 1 \Big/ \sqrt{1 + 6 \frac{d_n}{t} \frac{R_n^2}{R^2}}$$

where

d_n = Depth of Hub

R_n = Radius of Hub

t = Mirror Thickness

R = Mirror Radius

II. ANALYSIS METHOD

Since the main interest is the frequency of vibration, an energy method will be used. This will be checked against known frequencies to determine the accuracy.

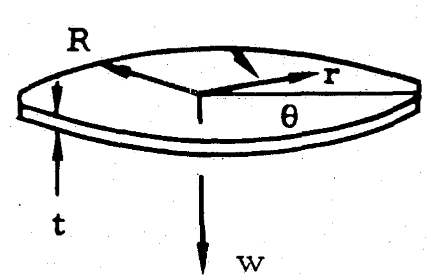
(a) Energy Method

The energy method of finding the natural frequencies consists of equating the strain energy of the plate at maximum amplitude to the kinetic energy at maximum velocity. For the circular plate these quantities are as follows: (assuming axisymmetric vibration)

Strain Energy = U =

$$= \int_o^R \int_o^{2\pi} \frac{1}{2} D \left\{ \left(\frac{\partial^2 w}{\partial r^2}\right)^2 + \frac{1}{r^2}\left(\frac{\partial w}{\partial r}\right)^2 + 2\nu \frac{1}{r}\left(\frac{\partial^2 w}{\partial r^2}\right)\left(\frac{\partial w}{\partial r}\right) \right\} rdrd$$

$$D = \frac{Et^3}{12\,(1 - \nu^2)}$$



$$\text{Kenetic Energy} = T = \omega^2 \int_o^R \int_o^{2\pi} \rho t\,(w)^2\, rdrd\theta$$

ω = Frequency in radians/second

In order to find the frequency a displacement function which satisfies the geometric boundary conditions is assumed. Carrying out the integration the frequency ω is determined.

(b) Particular Cases

(1) Simply support at outside edge (uniform thickness)

The assumed function must satisfy the condition

$$w = o \text{ at } r = R$$

Use

$$w = W_o \left(1 - \frac{r^2}{R^2}\right)$$

Carrying out the integrations:

$$U = D\pi 4 \, (1 + \nu) \frac{1}{R^2} W_o^2$$

$$T = \omega^2 \pi \frac{1}{6} \rho t R^2 W_o^2$$

$$\omega = \sqrt{\frac{E}{\rho}} \frac{t}{R^2} \sqrt{\frac{2}{1 - \nu}} \qquad \text{radians/second}$$

$$\boxed{f = \sqrt{\frac{E}{\rho}} \frac{t}{R^2} \frac{\sqrt{3}}{\alpha\pi}} \qquad \text{for } \nu = \frac{1}{3}$$

(2) Clamped at outside edge (uniform thickness)

For this case the assumed function must satisfy

$$w = o \text{ and } \frac{\partial w}{\partial r} = o \text{ at } r = R$$

Use

$$w = W_o \left(1 - \frac{r^2}{R^2}\right)^2$$

Carrying out the integrations

$$U = D\pi W_o^2 \frac{1}{R^2} \frac{32}{3}$$

$$T = \omega^2 \rho t\pi R^2 \frac{1}{10} W_o^2$$

$$\omega = \sqrt{\frac{E}{\rho}} \frac{t}{R^2} \sqrt{\frac{320}{36 (1 - \nu)}}$$

$$f = \sqrt{\frac{E}{\rho}} \frac{t}{R^2} \frac{\sqrt{10}}{2\pi} \qquad \text{for } \nu = \frac{1}{3}$$

(3) <u>Clamped at outside edge and supported at center</u> (uniform thickness)

For this case the assumed displacement must satisfy

$$w = o \text{ at } r = R \text{ and}$$

$$\left.\begin{aligned} w &= o \\ \frac{\partial w}{\partial r} &= o \end{aligned}\right\} \quad r = o$$

Use $$\omega = W_o \left(\frac{r^2}{R^2} - \frac{r^4}{R^4}\right)$$

Carrying out the integration

$$U = D\pi W_o^2 \frac{10}{R^2}$$

$$T = \rho t\pi \omega^2 W_o^2 R^2 \frac{1}{60}$$

$$\omega = \sqrt{\frac{E}{\rho}}\frac{t}{R^2}\frac{15}{2}$$

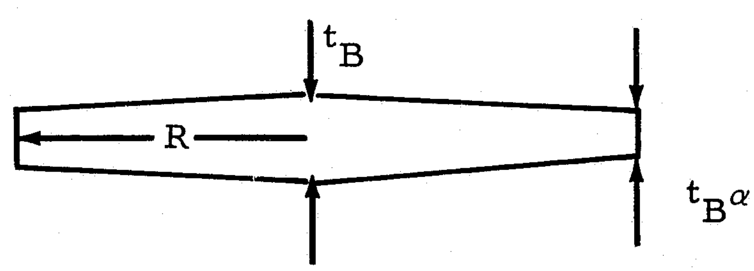
$$\boxed{f = \sqrt{\frac{E}{\rho}}\frac{t}{R^2}\frac{15}{4\pi}}$$

(4) Effect of Non-Uniform Thickness

Simple support at outside edge.

In this calculation it will be assumed that the thickness is a linear function of r.

$$t = t_B\ (1 - \alpha\frac{r}{R})$$



For the deflection

$$\omega = W_o\ (1 - \frac{r^2}{R^2})$$

Carrying out the integration

$$D = \frac{Et_B^3}{12\ (1 - \nu^2)}$$

$$U = D\pi\frac{4\ (1 + \nu)}{R^2}W_o^2\left(1 - 22 + \frac{3}{2}\alpha^2 - \frac{2}{5}\alpha^3\right)$$

$$T = \pi\rho\omega^2 W_o^2 t_B R^2 \frac{1}{6}\left[1 - \frac{16}{35}\alpha\right]$$

$$\omega = \sqrt{\frac{E}{\rho}}\frac{t_B}{R^2}\sqrt{\frac{2}{1 - \nu}}\sqrt{\frac{1 - 2\alpha + \frac{3}{2}\alpha^2 - \frac{2}{5}\alpha^3}{1 - \frac{16}{35}\alpha}}$$

Calculate an average thickness (by volume)

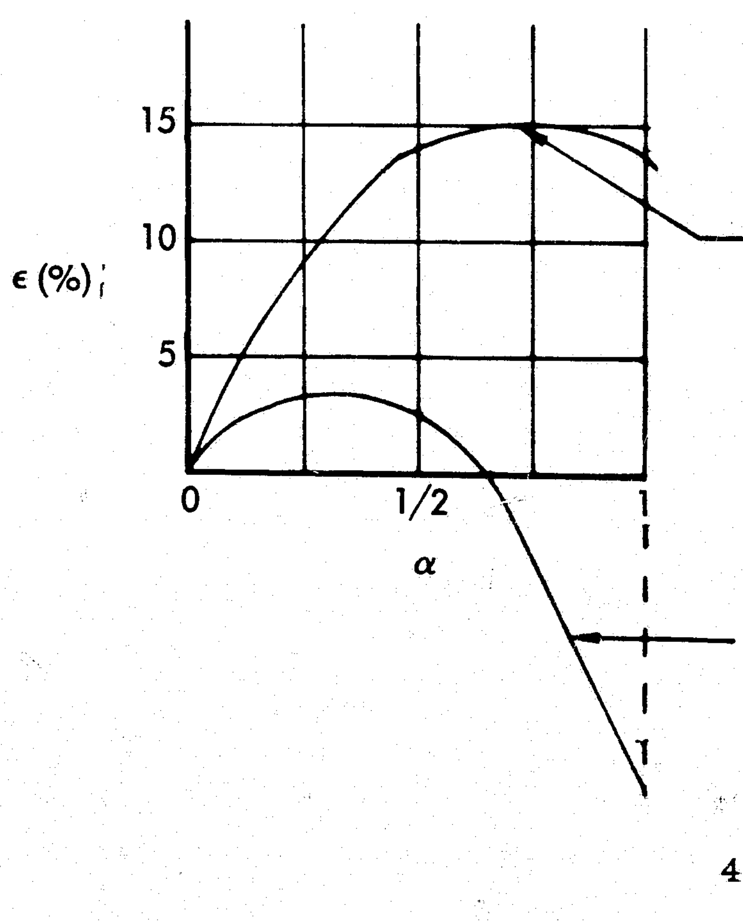
$$\pi R^2 t_a = \int_o^R t \, 2\pi r dr = t_8 \, 2\pi \; \frac{R^2}{2} - \alpha \frac{R^3}{3}$$

$$t_a = t_B \, (1 - \tfrac{2}{3}\alpha)$$

Therefore, the percent error by assuming an average thickness is given by the following

$$\text{percent error} = \epsilon = 1 - \frac{3}{3 - 2\alpha \cdot \sqrt{\dfrac{1 - 2\alpha + \frac{3}{2}\alpha^2 - \frac{2}{5}\alpha^3}{1 - \frac{16}{35}\alpha}}}$$

$$\epsilon = \frac{\omega_{exact} - \omega_{approx}}{\omega_{exact}} \times 100$$



error based on average thickness

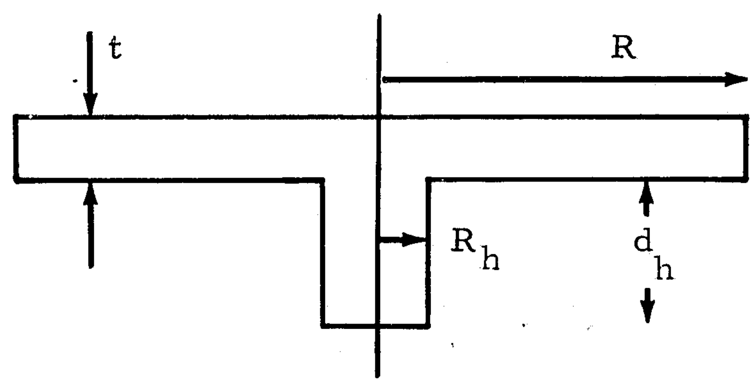
$$t_a = (1 - \tfrac{\alpha}{2}) \, t_B$$

error based on thickness giving same volume

$$t_a = (1 - \tfrac{2}{3}\alpha) \, t_B$$

(5) Effect of Hub Mass (simple support)

For this problem, the hub mass is added to the kinetic energy term



$$U = D\pi \frac{4}{R^2} (1 + \nu) W_o^2$$

$$T = \rho t \pi \omega^2 W_o^2 R^2 \frac{1}{6} + \rho \pi R_h^2 d_h \omega^2 W_o^2$$

$$\omega = \sqrt{\frac{E}{\rho}} \frac{t}{R^2} \sqrt{\frac{2}{1 - \nu}} \Bigg/ \sqrt{1 + 6 \frac{d_h}{t} \frac{R_h^2}{R^2}}$$

$$\frac{f \text{ (with hub)}}{f \text{ (no hub)}} = \frac{1}{\sqrt{1 + 6 \frac{d_h}{t} \frac{R_h^2}{R^2}}}$$

APPENDIX B

PHOTOHELIOGRAPH WEIGHT CALCULATIONS

APPENDIX B

PHOTOHELIOGRAPH WEIGHT CALCULATIONS

F. Bonwit

With the completion of a satisfactory telescope layout and the detailed design of certain critical components (such as the primary mirror, launch locks, etc.), it became practical to calculate more precise total weight, center of gravity and moments of inertia. The detailed weight calculations, in particular, are needed for initial stress analyses, and have been completed. The other items will follow shortly. The volume and weight was calculated for each component, structural member, fitting, bolt, etc. so that future changes in design or materials may be easily accommodated. Sub-totals are tabulated for comparison with strength analyses to indicated areas where weight savings may be realized. The target weight for the entire photoheliograph, in flight configuration, is 700 lbs. The earlier weight estimate, based on a tubular aluminum housing and a flat primary mirror, was within this limit. However, the new calculated weight is 855 lbs. The increase is partly due to changes in materials and partly to overdesign of primary structural members. Thoughtful redesign, where indicated by stress analysis and testing, should be able to reduce this substantially.

F. H. BONWIT — PREPARED BY — 7-10-68 — DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO.

CHECKED BY — DATE — PROJECT

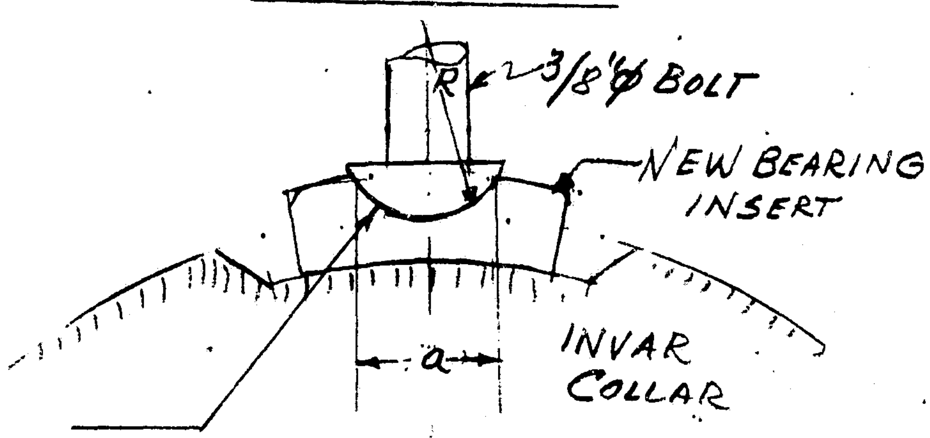
TITLE: STRUCTURAL INTEGRITY OF COLLAR ASSY—PRIMARY MIRROR A.T.M.

BEARING INSERT
FOR BEARING (CONT.D.

DESIGN RECOMMENDATION
TO RAISE M.S.

REF. DWG 10026241 & 10026261

$a = .50$
$R = .375$



NEW CRITICAL BEARING AREA
(PROJECTION): $A_p = \frac{\pi}{4} a^2 = .785 \times .50^2 = .196 \text{ IN}^2$

$P \cos 15° = 3{,}622 \text{ LBS}$

$$f_{br} = \frac{P \cos 15°}{A_p} = \frac{3{,}622}{.196} = 18{,}480 \text{ PSI}$$

$$F_{bry} = 58{,}000 \text{ PSI}$$

$$M.S. = \frac{F_{bry}}{f_{br}} - 1 = \frac{58{,}000}{18{,}480}$$

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT — PREPARED BY — 7-8-68 — DATE — JET PROPULSION LABORATORY — REPORT NO.

CHECKED BY — DATE — CALIFORNIA INSTITUTE OF TECHNOLOGY — PROJECT

TITLE: STRUCTURAL INTEGRITY OF COLLAR ASSY.-PRIMARY MIRROR-ATM

COLLAR SUPPORT

REF. DWG. 10026244
MATL. A-286

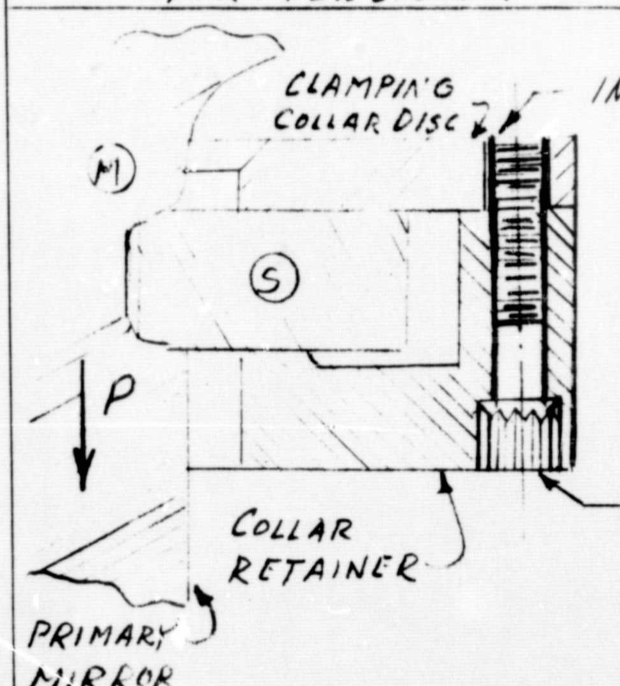
(6) CLOSE TOL. BOLTS (DS136-10-13L)

FOR TENSION:

ASSUMPTION:

(6) CLOSE TOL. BOLTS HOLD CLAMPING COLLAR DISC TO COLLAR RETAINER

$\boxed{\text{ASSUME: 50 G's}}$



WEIGHT OF (M) = 75.0 LBS
" " (S) = 3.0 LBS
ΣW = 78.0 LBS

$\boxed{F_{TU} = 160,000 \text{ PSI (T6)}}$

ULT TENSILE STRENGTH PER BOLT P_{TU} = 2,892 LBS

FOR (6) BOLTS: $\Sigma P_{BOLT} = 6 \times 2,892 = 17,352$ LBS

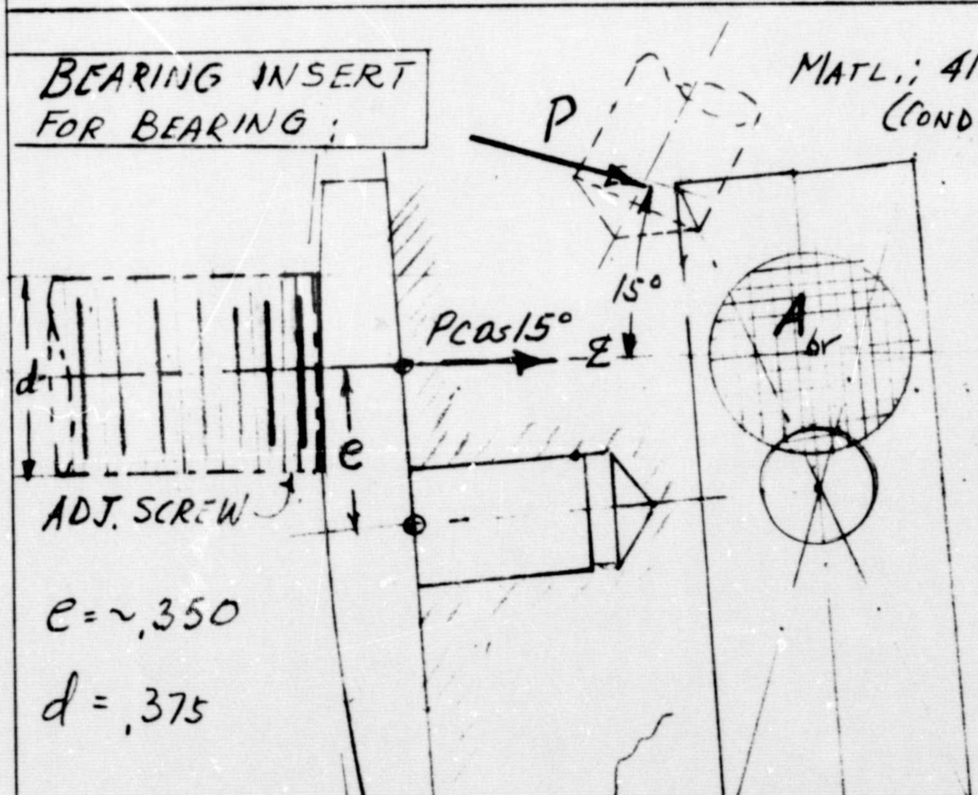
$P = \Sigma W \times 50 = 78.0 \times 50 = 3,900$ LBS

$$M.S. = \frac{\Sigma P_{BOLT}}{P} - 1 = \frac{17,352}{3,900} - 1 = \underline{\underline{3.45}}$$

BEARING INSERT FOR BEARING:

MATL.; 416 STAINL. STL (COND A/QQ763c)

REF. DWG 10026241-103 & DWG. 10026261



ASSUMPTION: ADJUSTMENT SCREW IN SYMMETRICAL ALIGNMENT WITH A.T.M. AXIS BUT IN ECCENTRICITY TO BEARING INSERT. (POSSIBLE MIRROR ADJ. POSITION)

$e = \sim .350$

$d = .375$

$$A_{br} = \frac{\pi}{4} d^2 = .785 \times (.375)^2 = .11 \text{ IN}^2$$

$P \cos 15° = 3,750 \times .9659 = 3622$

$$f_{br} = \frac{P \cos 15°}{A_{br}} = \frac{3622}{.11} = 32,927 \text{ PSI}$$

F_{TU} = 70,000 PSI; ASSUME F_{bry} = 66% F_{TU} = 58,000 PSI

$$M.S. = \frac{F_{bry}}{f_{br}} - 1 = \frac{58,100}{32,927} - 1 = \underline{\underline{.761}}$$ LOW !! SEE "RECOMMENDATION" NEXT PAGE

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONNIT — PREPARED BY	7-3-68 — DATE	JET PROPULSION LABORATORY	REPORT NO.
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

TITLE: INTEGRITY OF COLLAR ASSY. - PRIMARY MIRROR - A.T.M.

SUPPORT COLLAR

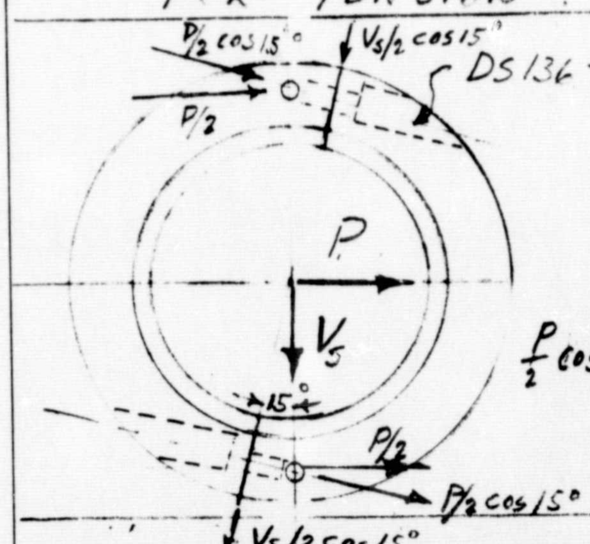
REF. DWG. 1002641
MATL.: A-286

(2) SELF LOCK BOLTS (DS136-31-8L)

FOR TENSION:

ASSUMPTION:
LOCK BOLTS - ALONE - HOLD
COLLAR SUPPT. TOGETHER (CONSERVATIVE)

$\boxed{F_{tu} = 160{,}000 \text{ PSI (T6)}}$



ULT. TENSILE STRENGTH PER BOLT $P_{TU} = 8{,}590$ LBS

FOR (2) BOLTS 17,180 LBS $= \Sigma P_{BOLT}$

$\boxed{\text{ASSUME } 50 G\text{'s}}$

$\frac{P}{2}\cos 15° + \frac{P}{2}\cos 15° = P\cos 15° = W_m \times \cos 15° \times 50 =$
$= 75.0 \times .9659 \times 50 = 3{,}622$

$$M.S. = \frac{\Sigma P_{BOLT}}{P\cos 15°} - 1 = \frac{17{,}180}{3{,}622} - 1 = \underline{3.74}$$

DS 136 BOLTS FOR SHEAR:

ASSUME: "SHEAR" = 60% OF F_{TU} = .60 × 160,000 = 96,000 PSI (S-5)

FOR S-5 BOLT: V_{S_U} = 7,290 LBS (SINGLE SHEAR PER BOLT)

FOR (2) BOLTS: $2V_s$ = 14,580 LBS

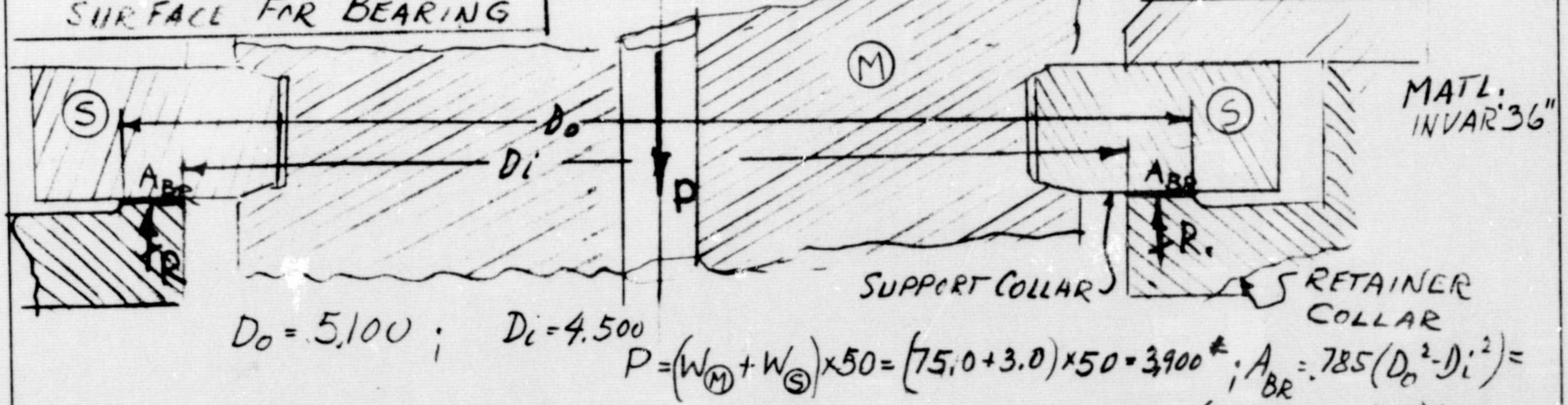
$2V_S \times \cos 15° = W_m \times \cos 15° \times 50 =$
$= 75.0 \times .9650 \times 50 = 3{,}622$ LBS

$$M.S. = \frac{2V_{SU}}{V_S \cos 15°} - 1 = \frac{14580}{3{,}622} - 1 = \underline{\underline{3.03}} \text{ (CONSERVATIVE)}$$

COLLAR RETAINER SURFACE FOR BEARING

PRIM. MIRROR

REF. DWG. 10026244



$D_o = 5.100$; $D_i = 4.500$

$P = (W_{(M)} + W_{(S)}) \times 50 = (75.0 + 3.0) \times 50 = 3{,}900\#$; $A_{BR} = .785(D_o^2 - D_i^2) =$
$.785(5.100^2 - 4.500^2) = 4.52 \text{ IN}^2$

$f_{BR} = \frac{P}{A_{BR}} = \frac{3{,}900}{4.52} = 862.83$ PSI

$\boxed{F_{bry} = 60{,}000 \text{ PSI (SEE PAGE 12)}}$

$$M.S. = \frac{F_{bry}}{f_{br}} = \frac{60{,}000}{862.83} - 1 = 68.54 \text{ (HIGH)}$$

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT — PREPARED BY | 7-2-68 — DATE | JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY | REPORT NO.

CHECKED BY | DATE | PROJECT

TITLE: STRUCTURAL INTEGRITY OF COLLAR ASSY.-PRIMARY MIRROR-A.T.M.

COLLAR SUPPORT

REF. DWG. 10026241

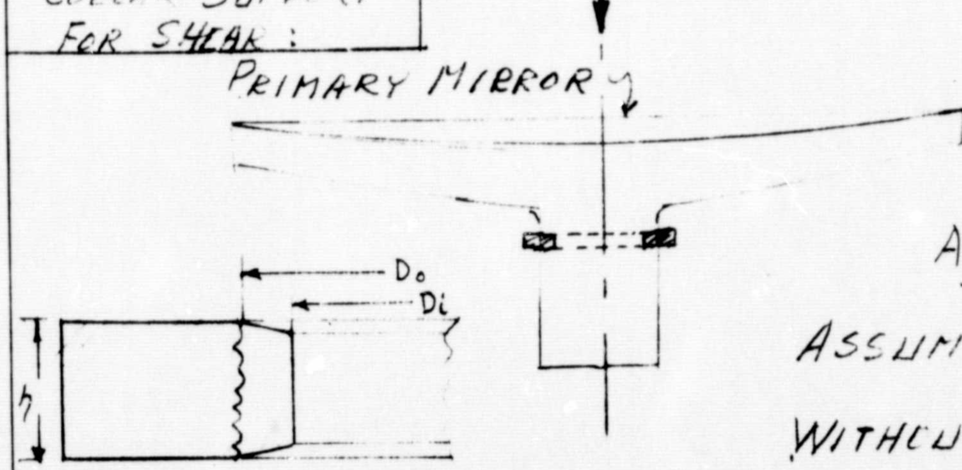
MATL.: INVAR "36"

$D_o = 3.950$; $D_i = 3.625$

$h = .635$

ASSUME 50 G's

COLLAR SUPPORT FOR SHEAR:



$A_s = D_o \pi \times h = 3.950 \times \pi \times .635 = 7.880 \text{ in}^2$

ASSUME THAT COLLAR SUPPORT ALONE - WITHOUT THE (10) LAUNCH LOCKS - IS TAKING THE ENTIRE BLAST-OFF LOAD OF THE MIRROR ASSEMBLY.

WEIGHT OF MIRROR: $W_M = \sim 75.0$

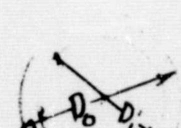
$P = W_M \times 50 = 75.0 \times 50 = 3{,}750$ LBS

$f_s = \frac{P}{A} = \frac{3{,}750}{7.88} = 475.59$ PSI

$\boxed{F_{su} = .60\, F_{tu} = .60 \times 65{,}000 = 42{,}250 \text{ PSI}}$

$M.S. = \frac{F_{su}}{f} - 1 = \frac{42{,}250}{475.89} - 1 = 87.751$ (HIGH)

COLLAR SUPPORT FOR BEARING PRESS.



$A_{br} = .785 (D_o^2 - D_i^2) = 1.933 \text{ IN}^2$

15.60 - 13.14

$P = 3{,}750$ LBS

$f_{br} = \frac{P}{A_{br}} = \frac{3{,}750}{1.933} = 1{,}940$ PSI

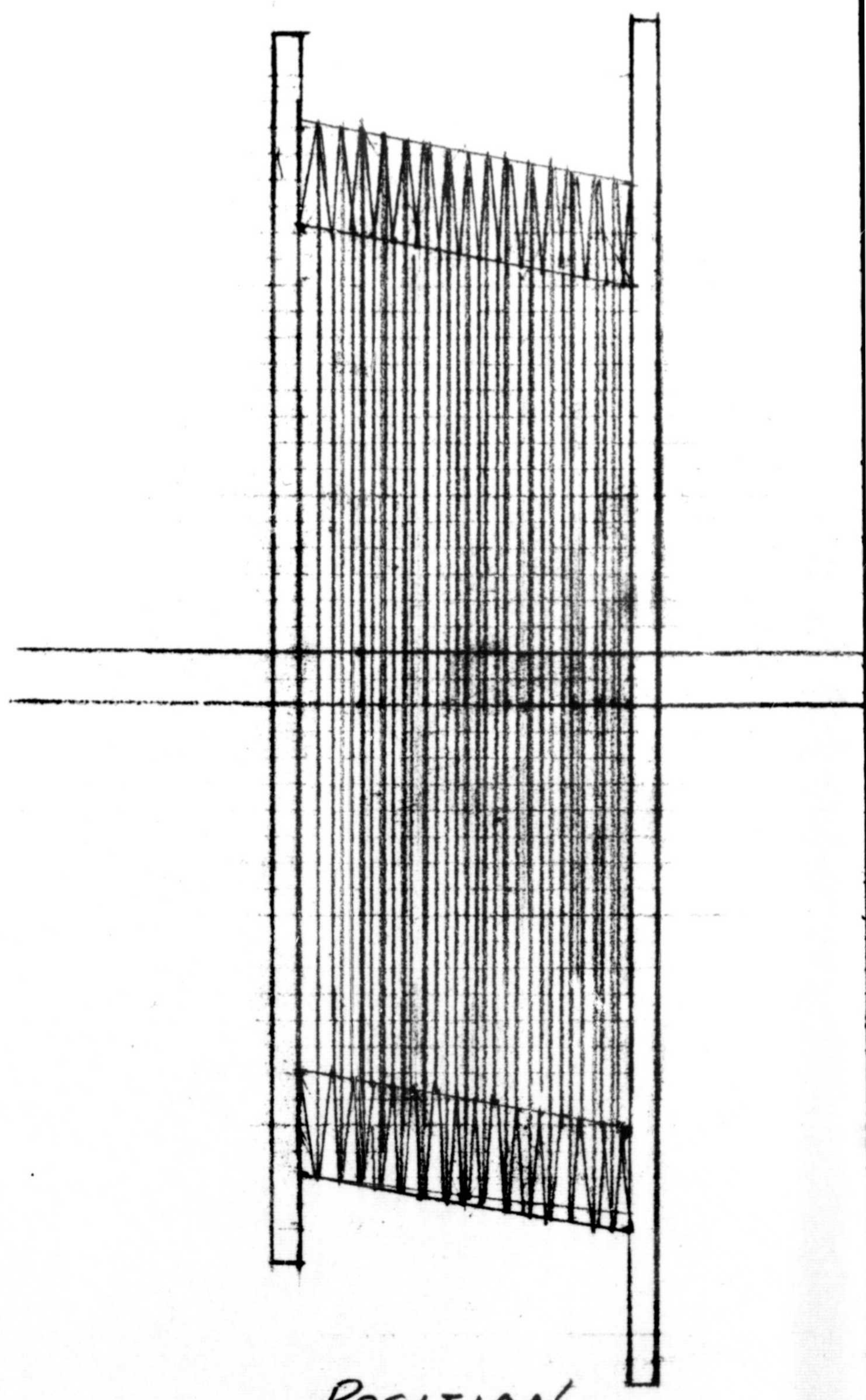
FOR STAINL. STL. (ANNEALED): $F'_{bry} = 50{,}000$ PSI, $F'_{ty} = 30{,}000$ PSI

FOR INVAR "36" (ANNEALED): $F_{ty} = 40{,}000$ PSI

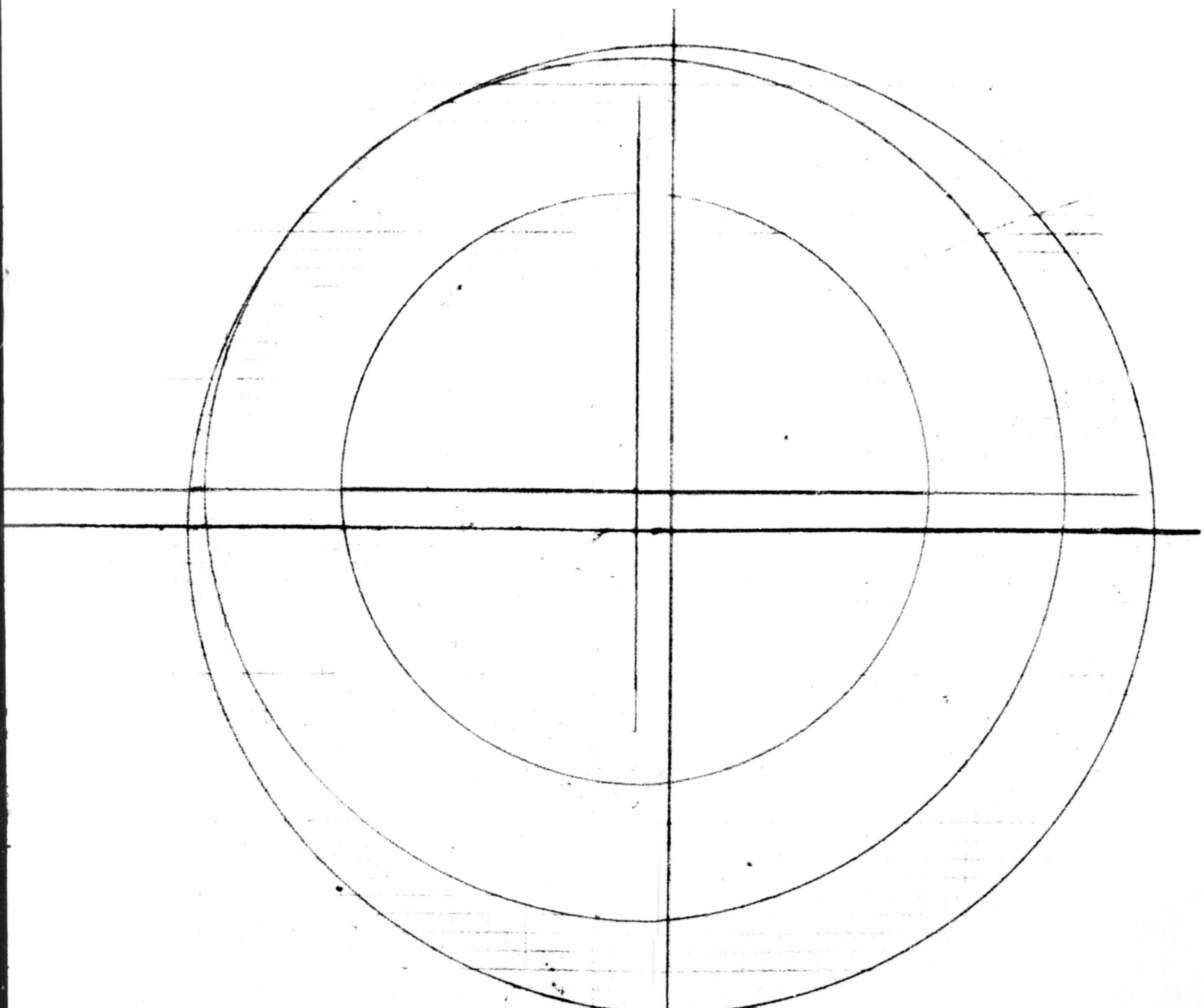
FOR INVAR "36" (ANNEALED): $F_{bry} = \frac{F'_{bry}}{F'_{ty}} \times F_{ty} = \frac{50{,}000}{30{,}000} \times 40{,}000 = 60{,}000$ PSI

$M.S. = \frac{F_{bry}}{f_{br}} - 1 = \frac{60{,}000}{1{,}940} - 1 = \underline{29.93}$ (HIGH - CONSERVATIVE!)

CLASSIFICATION



FOLDOUT FRAME 1



REF. DWG. 10026224

FOLDOUT FRAME 2

SY.

PREPARED BY	6-17-68 DATE	JET PROPULSION LABORATORY	REPORT NO.
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

TITLE

DWG. NO	SIZE		TITLE
			2ND DIAGONAL
1002613	D		MIRROR ASSY
14	D		HOLDER, MIRROR
15	C		HOLDER RING
16	C		PAD, MIRROR
17	C		TOP PAD
18	C		MIRROR
19	A		ADJ. PLATE
20	B		ADJ. SCREW
21	J	S1	HOUSING
22	J	S2	" DETAILS
23	C		BELLOWS ASSY.
24	J		HOUSING ASSY

CLASSIFICATION

JPL 0999-1-5 APR 66

F. H. Bonwit — PREPARED BY | 6-24-68 — DATE | JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY | REPORT NO.

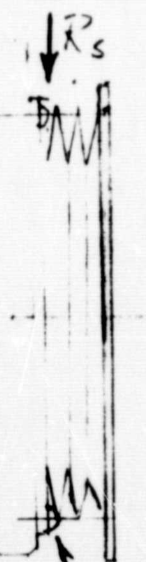
CHECKED BY | DATE | PROJECT

TITLE: STRUCTURAL INTEGRITY OF 2^{ND} DIAGONAL ASSY. – A.T.M.

(4) BELLOWS HOLDING SCREWS (MS 51957-28) FOR SHEAR:

REF DWG. 10026224

ASSUME 50 "G"S



WEIGHT OF BELLOWS AND 6.5 O.D. FLANGE:

$W = W_B + W_F = .992$ LBS

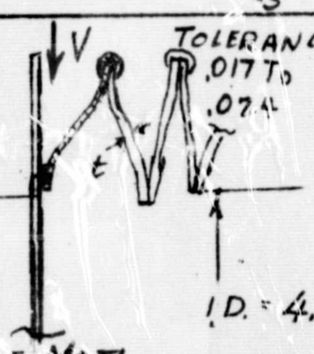
$R_s = \frac{W \times 50}{4} = \frac{.992 \times 50}{4} = 12.4$ LBS FOR EACH OF (4) SCREWS.

MAX. TENSILE STRENGTH 730 LBS PER EACH MS 51957 SCREW

ALLOWABLE SHEAR LOAD: $P_{SU} = .6 \times 730 = 438$ LBS (APPROX.)

$M.S. = \frac{P_{SU}}{R_s} - 1 = \frac{438}{12.6} - 1 = \underline{33.7}$

END CONVOLUTION OF BELLOWS FOR SHEAR:



ASSUME WELD THICKNESS: $t_W = .01$

THICKNESS OF CAPSULE MATERIAL:

$t = .007$ (THICKNESS OF CAPSULE MATL.

WEIGHT OF BELLOWS: $W_B = .75$ LBS

$\ell = ID \times \pi = 4 \times \pi$; $A = \ell \times t_W = 4\pi \times .01 = .126$

$V = \frac{P}{2}$; $\frac{P}{2} = \frac{1}{2} W_B \times 50 = .5 \times .75 \times 50 = 18.75$ LBS

$f_s = \frac{P}{2A} = \frac{18.75}{2 \times .126} = 74.40$ PSI

MATL. STAINLESS STL.

$F_{SU} = .6 F_{TU} = .6 \times 80{,}000000 = 48{,}000$ PSI

$M.S = \frac{F_{SU}}{f_s} - 1 = \frac{48{,}000}{74.4} - 1 = \underline{644.2}$ HIGH

NATURAL FREQUENCY OF BELLOWS:

$f_N = \frac{1}{2\pi} \sqrt{\frac{K}{m}}$; $K = 22$ (FROM CATALOG)

ASSUME NO "G"S

$m = \frac{W_B}{g} = \frac{.75}{386} = .00194$; $f_N = \frac{1}{2\pi} \sqrt{\frac{22}{.00194}} = \underline{16.95 \text{ CPS}}$

$f_N = \frac{1}{2\pi} \times \sqrt{\frac{192 \times EI}{m \ell^3}}$; $\ell = 1.84$; $m = .194 \times 10^{-2} \times 50 = 9.7 \times 10^{-2}$; $E = 30 \times 10^6$ PSI; $I = .049 \times (4.97^4 - 4.0^4) = 16.95 \text{ IN}^4$

$f_N = \frac{1}{2\pi} \times \sqrt{\frac{192 \times 30 \times 10^6 \times 16.95}{9.7 \times 10^{-2} \times 6.22}} = \underline{64{,}025 \text{ CPS}}$ (NOT REALISTIC)

ASSUME: 50 G'S

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT — PREPARED BY | 6-21-68 — DATE | JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY | REPORT NO.

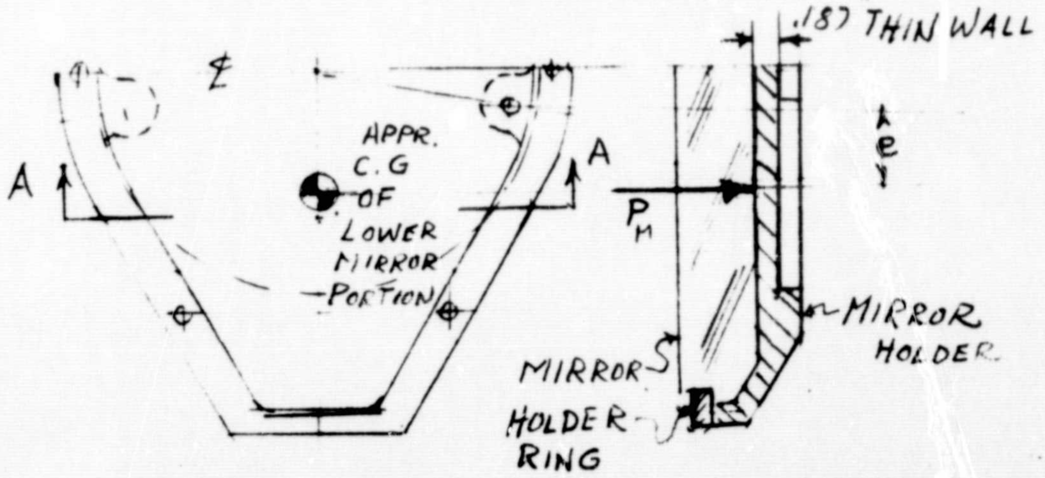
CHECKED BY | DATE | PROJECT

TITLE STRUCTURAL INTEGRITY OF 2ND DIAGONAL ASSY. - A.T.M.

REF. DWG. 10026213

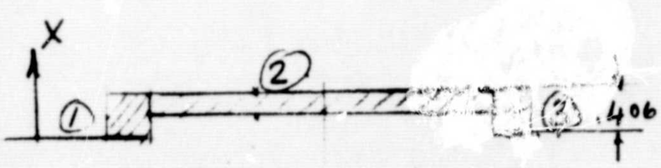
MIRROR HOLDER

"THIN WALL OF MIRROR HOLDER FOR SHEAR (BELOW MIRROR ADJ. SCREWS)



$e = .7$

CONSIDER LOWER PORTION OF HOLDER A CANTILEVER BEAM — OF INVERTED (⌐¬) CHANNEL SHAPE, LOWER PORTION OF MIRROR MASS CAUSING A BENDING MOMENT:



SECTION "A-A"

$M_{M_1} = P_M \times e$

$M_{M_1} = 6.1 \times .7 = 4.27$ $\boxed{\text{ASSUME } 50\text{ G's}}$

ITEM	AREA	A	d	Ad	Ad^2	I_0
1	.4×.406	.1624	.203	.0330	.0067	.0022
2	3.0×.187	.5610	.313	.1736	.0550	—
3	.4×.406	.1624	.203	0330	.0067	.0022
	ΣA	.8858		.2416	.0684	.0044

$W_M = .305$ LBS; $W_{M_1} = .40 \times .305 = .122$ LBS

$P_{M_1} = .122 \times 50 = 6.10$ LBS

$M_{M_1} = 6.1 \times .7 = 4.27$ IN LBS

$\bar{x} = \frac{\Sigma AD}{\Sigma A} = \frac{.2416}{.8858} = .2727;\ \bar{x}^2 = .074$

$I = I_0 + \Sigma Ad^2 - \Sigma A \bar{x}^2 = .0044 + .0684 - (.8858 \times .074) = .0073\ IN^4$

$f_b = \frac{M_{M_1}}{I} \cdot c = \frac{4.27 \times .2727}{.0073} = 159.51$ PSI

$\boxed{F_{tu} = 42\,000 \text{ PSI}}$

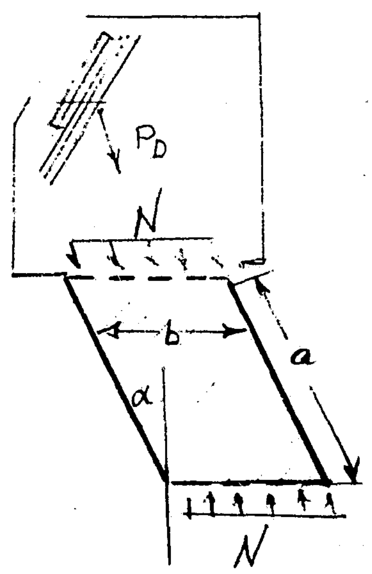
$M.S. = \frac{F_{tu}}{f_b} - 1 = \frac{42000}{160} - 1 = \underline{\underline{262}}$ (HIGH)

F H KEMNIT	6-20-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE
STRUCTURAL INTEGRITY OF 2ND DIAGONAL ASSY. – A.T.M.

HOUSING

REF. DWG 10026221



SKEW (SIDE WALL) PLATES WITH ALL EDGES CLAMPED FOR LIMIT BUCKLING LOAD;

$\eta = 1.0$; $\alpha = 23°$ $\quad a = 5.7$; $b = 4.2$

$E = 10 \times 10^6$ PSI $\quad t = .09$

$\nu = .3$

$$N_{CR}/\eta = K\frac{\pi^2 D}{b^2}; \quad D = \frac{E \times t^3}{12(1-\nu^2)} = \frac{10^7 \times (.09)^3}{12(1-.3^2)} = = 668.50$$

[FIND "K" FOR $\frac{a}{b} = \frac{5.7}{4.2}$ FROM NORTHROP STRESS MANUAL CURVE 304. 4-1]: 8.8

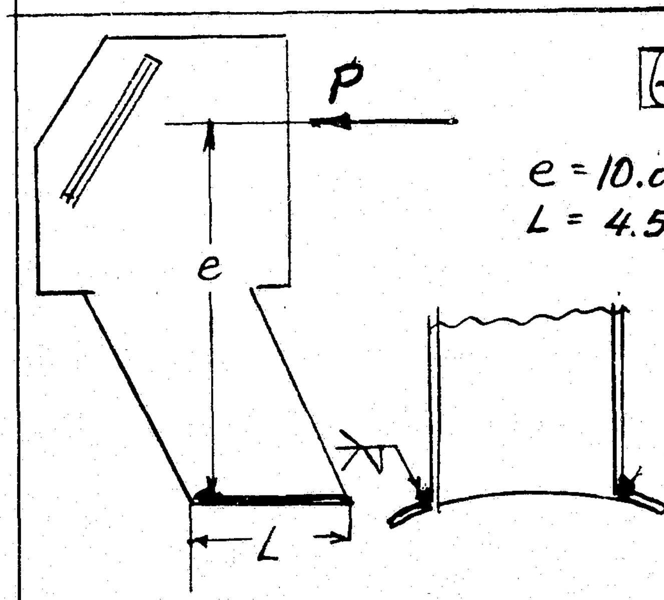
$$N_{CR}/_{1.0} = \frac{8.8 \times \pi^2 668.50}{(4.2)^2} = \underline{3291.2 \text{ LBS}} \text{ (FOR EA. WALL)}$$

W_D, = WEIGHT OF TOTAL 2ND DIAGONAL MIRROR ASSEMBLY, INCL. BELLOWS MINUS HALF OF HOUSING = 5.304 – 1.265 = 4.039 LBS

$P_D = W_D \cos\alpha \times 50 = 4.039 \times .9205 \times 50 = \underline{186.5 \text{ LBS}}$

ASSUME 50 "G"s

$$M.S. = \frac{2N_{CR}}{P_D} - 1 = \frac{3291.2 \times 2}{186.5} - 1 = \underline{\underline{34.3 \text{ (HIGH)}}}$$



(2) 3/8" FILLET WELDS FOR ALLOWABLE LOAD P_{ALL}

$e = 10.0$
$L = 4.5$

$P_D = W_D \times 50 = 5.304 \times 50 = 265.20$ LBS

LENGTH OF THROAT(S); $T = .375 \times .707 = .265$

SHEARING STRESS: $V = P_{ALL} \div (2 \times 4.5 \times .265) = .42 P_{ALL}$

BENDING STRESS: $f_b = (P_{ALL} \times e) \div \frac{2 \times 4.5^2 \times .265}{6} = 5.59 \times P_{ALL}$

$f = \sqrt{V^2 + f_b^2} \leq 11{,}300 \text{ PSI} = \sqrt{.42^2 + 5.59^2} \times P = 5.61P$

$P_{ALL} = \underline{2{,}016 \text{ LBS}}$

$$M.S. = \frac{P_{ALL}}{P_D} - 1 = \frac{2{,}015.7}{265.2} - 1 = \underline{6.60}$$

CHECK WITH FORMULA: $\quad P_{ALL} = \frac{16{,}000\,DL}{\sqrt{1 + \left(\frac{6e}{L}\right)^2}} = \frac{16{,}000 \times .375 \times 4.5}{\sqrt{1 + \left(\frac{6 \times 10}{4.5}\right)^2}} = \underline{2018 \text{ LBS}}$

D = .375 (WELD)

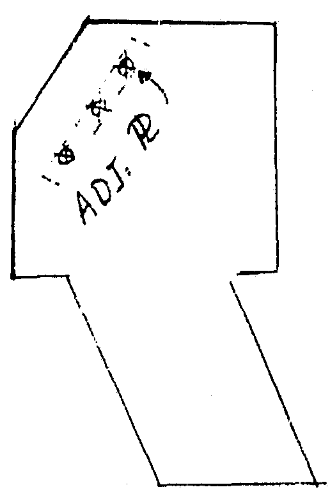
F. H. BONWIT	6-19-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE STRUCTURAL INTEGRITY OF 2^{ND} DIAGONAL ASSY. – A.T.M.

HOUSING

REF. DWG. 10026221

ASSUME 50 "G"



P

WEIGHT OF 2^{ND} DIAG. ASSY, INCL. MIRROR, HOLDER, PAD, ADJUSTMT. PLATE ETC.: $W_d = 1.682$ LBS

$V_s = P = 50W = 50 \times 1.682 = 84$ LBS

6-32 (MS. 51957) – MIN. TENS. = 730 LBS OR 80,000 PSI

6 - MIRROR FASTENING SCREWS – FOR SHEAR

MATL.: STAINL. STL.

$F_{su} =$ APPR. 60% $F_{tu} = .6 \times 80{,}000 = 48{,}000$ PSI (301 SS.)

$P_{su} = .6 \times 730 = 438$ LBS

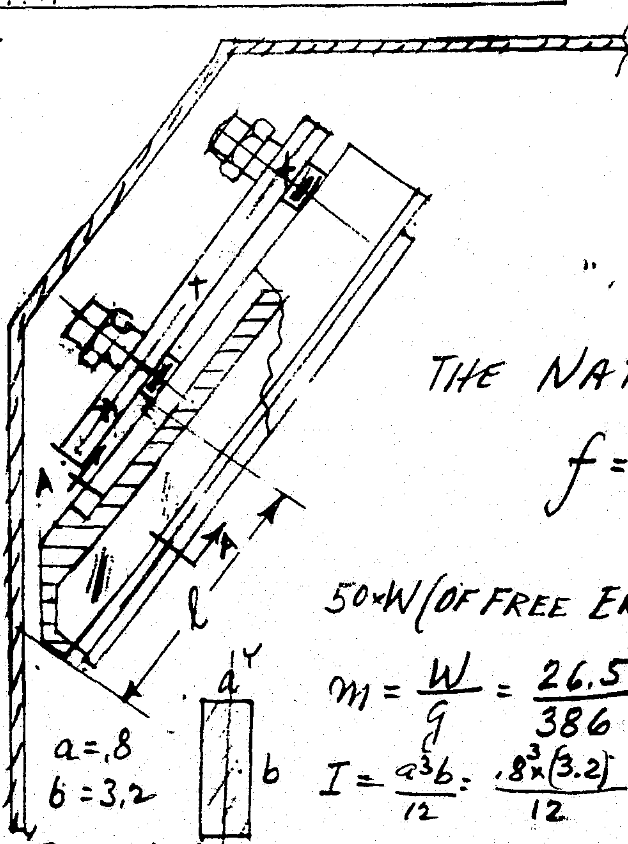
V_s' TAKEN UP BY (6) SCREWS

$V_{s_1} = \frac{V_s}{6} = \frac{84}{6} = 14$ LBS FOR EACH SCREW

$M.S. = \frac{P_{su}}{V_{s_1}} - 1 = \frac{438}{14} - 1 = \underline{\underline{30.1 \text{ (HIGH)}}}$

REF. DWG. 10026221

FREE END OF MIRROR ASSY FOR ITS NATURAL FREQUENCY



CONSIDER THE FREE END (LENGTH "ℓ") OF MIRROR ASSY. A CANTILEVER BEAM "CLAMPED" WITH ITS ONE END TO THE ADJUSTMENT PLATE.

$E_{MIRR.} = 10.5 \times 10^6$ PSI
$E_{AL} = 10. \times 10^6$ PSI

THE NATURAL FREQUENCY IS:

$$f = \frac{1}{2\pi}\sqrt{\frac{3E'I}{m\,\ell^3}}, \quad \text{WHERE: } \ell = \sim 2.00;\ E' = \frac{E_{AL} + E_M}{2} = 10.25 \times 10^6 \text{ PSI}$$

$50 \times W$ (OF FREE END) APPR. = 40% OF $W_{ASSY} \times 50 = .4 \times 1.325 \times 50 = 26.5$ LBS

$m = \frac{W}{g} = \frac{26.5}{386} = .0685$ LB, SEC²/IN

$I = \frac{a^3 b}{12} = \frac{.8^3 \times (3.2)}{12} = .1365$

$$f = \frac{1}{2\pi}\sqrt{\frac{3 \times 10.25 \times 10^6 \times .1365}{.0685 \times 2.0^3}} =$$

$f = \underline{\underline{440.5 \text{ CPS.}}}$

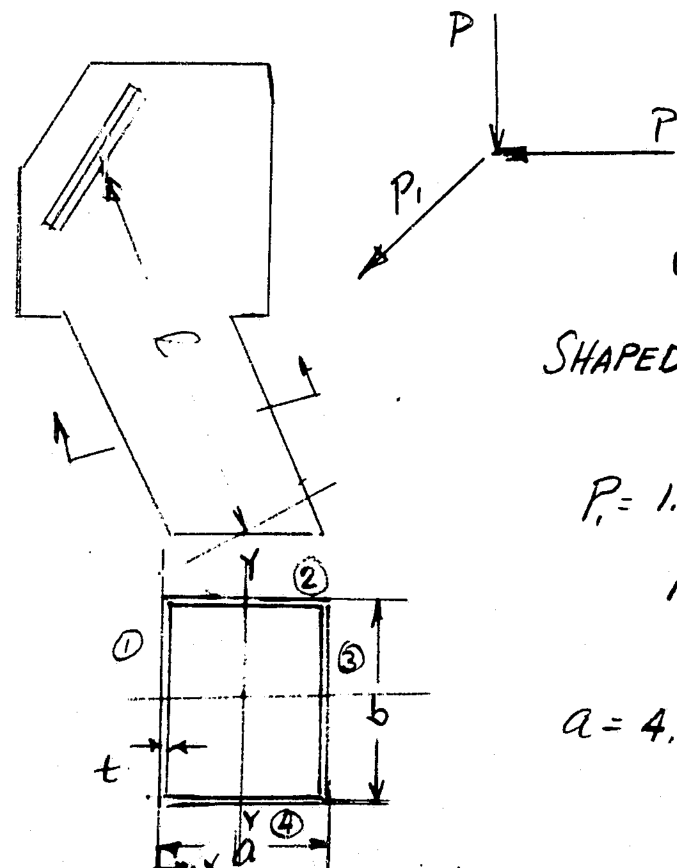
(CONSERVATIVE)

PREPARED BY	DATE		REPORT NO.
F.H. BONNIT	6-18-68	JET PROPULSION LABORATORY	
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

TITLE STRUCTURAL INTEGRITY OF 2ND DIAGONAL ASSY. – ATM

REF. DWG 10026224

ASSUME 50 "G"



$\ell = 10.0$

CONSIDER AS A CANTILEVER, BEAM (BOX SHAPED WITH CONCENTRATED LOAD "P" AT FREE END

$P_1 = 1.414P = 1.414 W_D \times 50 = 1.414 \times 5.304 \times 50 = 375$ LBS

$M_{MAX} = P\ell = 375 \times 10 = 3{,}750$ IN LBS

$a = 4.0$; $b = 5.0$; $t = .090$ (TYP.)

WALLS FOR BENDING

$c = \frac{a}{2} = 2.0$

$f_b = \frac{Mc}{I} = \frac{3{,}750 \times \cancel{2.0}}{\cancel{4.40}} =$

1,710 PSI

ITEM	AREA	A	d	Ad	Ad^2	I_o
1	5.0×.09	.45	.045	.020	.0009	—
2	3.82×.09	.34	2.0	.68	1.36	.48
3	5.0×.09	.45	3.955	1.780	7.040	—
4	3.82×.09	.34	2.0	.68	1.36	.48
		1.58		3.16	9.76	.96

$\bar{X} = \frac{\Sigma AD}{\Sigma A} = \frac{3.160}{1.58} = 2.0$, $\bar{X}^2 = 4.0$

$I = I_o + \Sigma Ad^2 - \Sigma A\bar{X}^2 = .96 + 9.76 - (1.58 \times 4.0) = \cancel{4.40}$ IN^4

$F_{tu} = 42{,}000$ PSI (6061-T6 AL.)

$M.S. = \frac{F_{tu}}{f_b} - 1 = \frac{42{,}000}{1{,}710} - 1 = \underline{\underline{23.6}}$ (HIGH)

F.H. BONWIT — PREPARED BY | 6-18-68 — DATE | **JET PROPULSION LABORATORY** | REPORT NO.

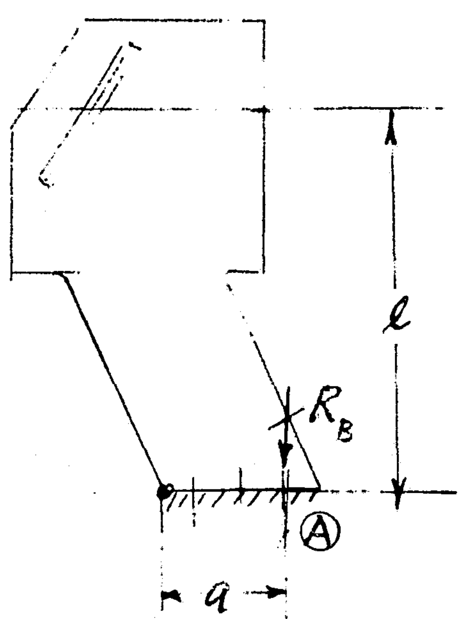
CHECKED BY | DATE | **CALIFORNIA INSTITUTE OF TECHNOLOGY** | PROJECT

TITLE: STRUCTURAL INTEGRITY - 2ND DIAGONAL ASSY. - ATM

HOUSING — REF. DWG. 10026224

$\ell = 9.25$; $a = 3.8$

ASSUME 50 G's



TOTAL WEIGHT OF ASSY. : $W_D = 5.304$ #

CONSIDER AS A CANTILEVER BEAM WITH A CONCENTRATED LOAD "P" AT FREE END

$$P = W_D \times 50 = 5.304 \times 50 = 265.20 \text{ LBS}$$

$$M_{MAX} = P\ell = 265.2 \times 9.25 = 2,430 \text{ IN LBS}$$

BASE SCREWS FOR TENSION

ASSUME ONLY (2) OPPOSING SCREWS (#8-32)-T-6 (160 KSI) @ (A) REACT TO M_{MAX}; $M_{MAX} = R_B \times a$ (PRYING-OFF MOMENT)

$$R_B = \frac{M_{MAX}}{a} = \frac{2,430}{3.8} = 640\,\# \text{ OR } R_{B_1} = 320\,\# \text{ (FOR EACH SCREW)}$$

F_{tu} = ULT. TENSILE STRENGH: 1,957 LBS

$$M.S. = \frac{F_{ULT}}{R_{B_1}} - 1 = \frac{1957}{320} - 1 = \underline{5.12}$$

THIS EXCEEDS "TENSIONAL" M.S. of 2.0 PLUS "VIBRATION" OR FATIGUE" M.S of 2.5 OR TOTAL M.S : 2×2.5 = 5

SCREWS FOR SHEAR

$V = 265.2$ LBS

RESISTED BY AT LEAST (2) SCREWS (CONSERVATIVE)

$R_S = \tfrac{1}{2}V = 132.6$ (EA.)

F_{SU} = ULT. SINGLE SHEAR STRENGTH; 2,007 (FOR #8-32 SCREWS) (FOR S-4 - 95,000 PSI

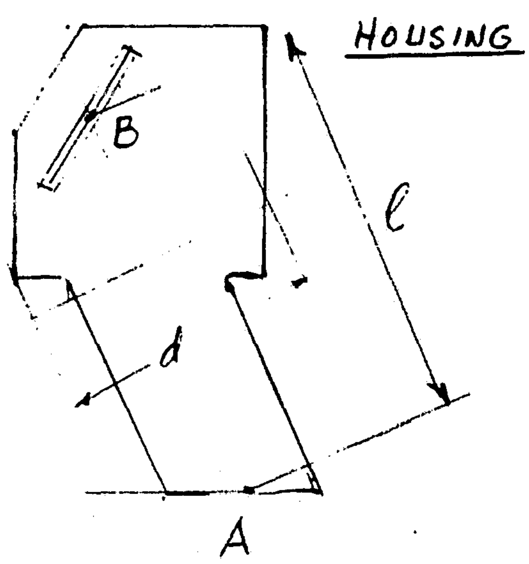
$$M.S. = \frac{F_{SU}}{R_S} - 1 = \frac{2,007}{132.6} - 1 = \underline{14.1} \text{ (HIGH)}$$

CLASSIFICATION — JPL 0999-1-S APR 66

F. H. BONWIT — PREPARED BY — 6-17-68 — DATE
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
CHECKED BY — DATE — REPORT NO. — PROJECT

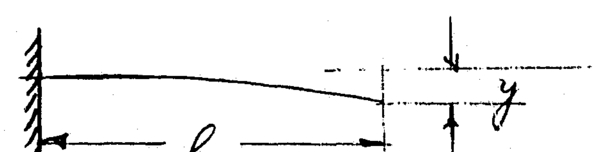
TITLE NATURAL FREQUENCY OF 2ND DIAGONAL – ATM

REF. DWG. 10026224



TO FIND FREQUENCY OF VIBRATION OF 2ND DIAGONAL CONSIDER THE TWO SIDE WALLS OF HOUSING (BACK AND FRONT-OUT OF THE PLANE ON SKETCH) AS A LIGHT CANTILEVER BEAM OF LENGTH "ℓ" UNDER A CONCENTRATED LOAD "P".

STATICAL DEFLECTION IS $\Delta = \frac{P\ell^3}{3EI}$; THEN



$k = \frac{P}{\Delta} = \frac{3EI}{\ell^3}$

THE NATURAL FREQUENCY THEN IS:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{3EI}{m\ell^3}}$$

ASSUME: NO "Gs"

WHERE: $\ell = \sim 10.7$; $E_{AL.} = 10\times10^6$ PSI, $P = W$ (TOTAL HOUSING INCL. 2ND DIAGONAL) $= 5.304$ LBS

$m = \frac{W}{g} = \frac{5.304}{386} = .014$ LBS·SEC²/IN ; $d = \sim 5.0$; $b = 2t = 2\times.09 = .18$;

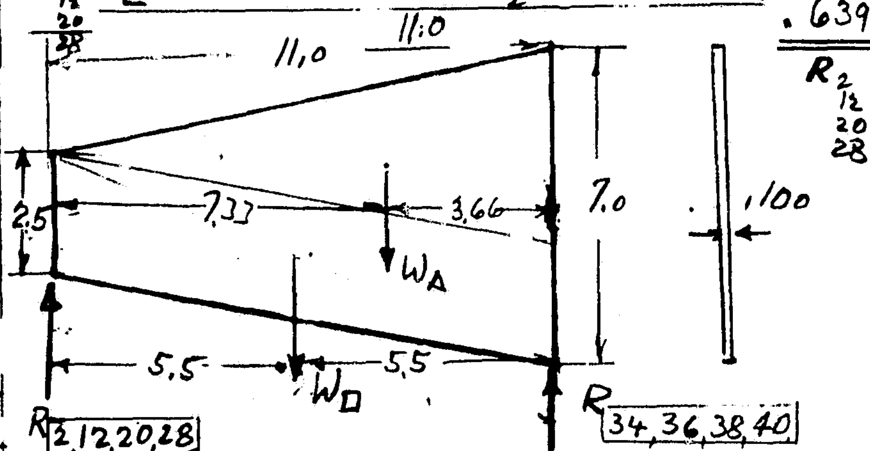
$I = \frac{bd^3}{12} = \frac{.18\times5^3}{12} = 1.88$ IN⁴; $f = \frac{1}{2\pi}\sqrt{\frac{3\times10\times10^6\times1.88}{.014\times(10.7)^3}} = 288.67$ Cyc/SEC

1225

F H Bonivit	6-7-68	JET PROPULSION LABORATORY		
PREPARED BY	DATE		REPORT NO.	
		CALIFORNIA INSTITUTE OF TECHNOLOGY		
CHECKED BY	DATE		PROJECT	

TITLE WEIGHT ANALYSIS – SECONDARY MIRROR – ATM

$$R_{\substack{2\\12\\20\\28}} = \frac{\left[\left(2.5 \times 11.0 \times .1 \times 5.5\right)^{15.125} + \left(\frac{11.0 \times 4.5}{2} \times .1 \times 3.66\right)^{9.0585}\right] \times .291}{11.0} = .639^{\#}$$



$R_{\substack{2\\12\\20\\28}}$

$$R_{\substack{34\\36\\38\\40}} = \frac{\left[2.5 \times 11.0 \times .10 \times 5.5 + \left(\frac{11.0 \times 4.5}{2} \times .1 \times 7.33\right)\right] \times .291}{11.0} =$$

$$R_{34,36,38,40} = .880^{\#}$$

TIE		W_{LBS}	ΣW_{LBS}
2 – 4 (3)	$\frac{4.7 \times 1.5 \times 3.2 \times .098}{2} =$	1.105	
2 – 33 (34)	$\frac{4.7 \times 1.5 \times 4.4 \times .098}{2}$	1.520	
2 – 34 (2)	$\frac{W_{\square} + W_{\Delta}}{11.0} \times .291$	.638	
2			3.263
4 – 2 (3)	$\frac{4.7 \times 1.5 \times 3.2 \times .098}{2} =$	1.105	
4 – 6 (4)	$\frac{6.5 \times 1.5 \times 5.1 \times .098}{2}$	2.437	
4	⟶		3.542
6 – 4 (4)	$\frac{6.5 \times 1.5 \times 5.1 \times .098}{2} =$	2.437	
6 – 8 (11)	$\frac{6.5 \times 1.5 \times 4.8 \times .098}{2} =$	2.295	
6	⟶		4.732
8 – 6 (11)	$\frac{6.5 \times 1.5 \times 4.8 \times .098}{2} =$	2.295	
8 – 10 (12)	$\frac{4.7 \times 1.5 \times 4.0 \times .098}{2} =$	1.381	
8	⟶		3.676
10 – 8 (12)	$\frac{4.7 \times 1.5 \times 4.0 \times .098}{2} =$	1.381	
10 – 12 (13)	$\frac{4.7 \times 1.5 \times 6.4 \times .098}{2}$	2.218	
10	⟶		3.599
12 – 10 (13)	$\frac{4.7 \times 1.5 \times 6.4 \times .098}{2}$	2.218	
12 – 14 (14)	$\frac{6.5 \times 1.5 \times 6.2 \times .098}{2}$	2.960	
12 – 36 (36)		.638	
12			5.816

TIE		W	
14 – 12 (14)	$\frac{6.5 \times 1.5 \times 6.2 \times .098}{2} =$	2.960	
14 – 16 (15)	$\frac{6.5 \times 1.5 \times 5.0 \times .098}{2} =$	2.390	
14	⟶		5.350
16 – 14 (15)	$\frac{6.5 \times 1.5 \times 5.0 \times .098}{2} =$	2.390	
16 – 18 (16)	$\frac{1.75 \times 1.5 \times 3.2 \times .098}{2} =$	.412	
16	⟶		2.802
18 – 16 (16)	$\frac{1.75 \times 1.5 \times 3.2 \times .098}{2} =$	.412	
18 – 20 (26)	$\frac{4.7 \times 1.5 \times 5.1 \times .098}{2}$	1.760	
18	⟶		2.172
20 – 18 (26)	$\frac{4.7 \times 1.5 \times 5.1 \times .098}{2} =$	1.760	
20 – 21 (27)	$\frac{4.7 \times 1.5 \times 35 \times .098}{2} =$	1.208	
20 – 38 (37)		.638	
20	⟶		3.606

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BONWIT PREPARED BY	6-10-68 DATE	JET PROPULSION LABORATORY	REPORT NO.
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

TITLE WEIGHT ANALYSIS - SECONDARY MIRROR - ATM

TIE		W	ΣW	TIE		W	ΣW
21 27 20	$\frac{4.7 \times 1.5 \times 3.5 \times .098}{2}$	1.208		33 34 32	$\frac{1.75 \times 1.5 \times 5.0 \times .098}{2}$	.643	
21 28 22	$\frac{6.5 \times 1.5 \times 5.0 \times .098}{2}$	2.390		33 35 2	$\frac{4.7 \times 1.5 \times 4.4 \times .098}{2}$	1.520	
21	⟶		3.598	33	⟶		2.163
22 28 21	$\frac{6.5 \times 1.5 \times 5.0 \times .098}{2}$ =	2.390		34 2 2		.880	
22 29 24	$\frac{6.5 \times 1.5 \times 5.5 \times .098}{2}$ =	2.622		34 - 42	1/4 SECONDARY MIRROR $1/4\, W_{SM} = 5.592/4$	1.398	
22	⟶		5.012	34	⟶		2.278
24 29 22	$\frac{6.5 \times 1.5 \times 5.5 \times .098}{2}$ =	2.622		36 36 12		.880	
24 30 26	$\frac{4.7 \times 1.5 \times 3.3 \times .098}{2}$ =	1.140		36 - 42	$1/4\, W_{SM} = 5.592/4$	1.398	
24	⟶		3.762	36	⟶		2.278
26 30 24	$\frac{4.7 \times 1.5 \times 3.3 \times .098}{2}$ =	1.140		38 37 20		.880	
26 31 28	$\frac{4.7 \times 1.5 \times 6.4 \times .098}{2}$ =	2.211		38 - 42	$1/4\, W_{SM} = 5.592/4$	1.398	
26	⟶		3.351	38			2.278
28 31 26	$\frac{4.7 \times 1.5 \times 6.4 \times .098}{2}$ =	2.211		40 38 28		.880	
28 32 30	$\frac{6.5 \times 1.5 \times 6.2 \times .098}{2}$ =	2.970		40 - 42	$1/4\, W_{SM} = 5.592/4$	1.398	
28 38 40		.638		40			2.278
28	⟶		5.819	42 - 34	$1/4\, W_{SM} = 5.592/4$	1.398	
30 32 28	$\frac{6.5 \times 1.5 \times 6.2 \times .098}{2}$	2.970		42 - 36		1.398	
30 33 32	$\frac{6.5 \times 1.5 \times 4.9 \times .098}{2}$ =	2.340		42 - 38		1398	
				42 - 40		1.398	
				42			5.592
30	⟶		5310	44		No WT.	
32 33 30	$\frac{6.5 \times 1.5 \times 4.9 \times .098}{2}$	2.340		46, 48, 50			
32 34 33	$\frac{1.75 \times 1.5 \times 5.0 \times .098}{2}$	.643		52, 54			
32	⟶		2983	56, 58			

15.

CLASSIFICATION

JPL 0999-1-5 APR 66

F. H. [illegible] — PREPARED BY | 6-11-68 — DATE | **JET PROPULSION LABORATORY** | REPORT NO.

CHECKED BY | DATE | **CALIFORNIA INSTITUTE OF TECHNOLOGY** | PROJECT

TITLE WEIGHT ANALYSIS - HOUSING TRUSS ATM

No.	TIE		W_{LBS}	ΣW_{LBS}
24	60-68	2"φ TUBING RING Wt = 10.0; 15°; $\frac{15}{360} = .0417$		
		$\frac{.0417 \times 10.0}{2}$ =	.21	
217	60-352	(15°) : $\frac{.0417 \times 10.0}{2}$	.21	
	60	⟶		.42
25	68-70	($60° = \frac{60}{360} = .166$) TUBE RING WT; 2"φ TUBE: $\frac{.166 \times 10.0}{2}$	.83	
		2" TUBE FITTG. (DOUBLE)	1.37	
24	68-60	(15°) : $\frac{.0417 \times 10.0}{2}$	.21	
10	68-88	1"φ TUBE DIAG.: $(\frac{.44}{2})$ =	.22	
39	68-90	" " : $\frac{.44}{2}$ =	.22	
	68	⟶		2.85
25	70-68	(60°)-2"φ TUBE RING: $\frac{.166 \times 10}{2}$	.83	
		2" TUBE FITTG. (DOUBLE)	1.37	
5	70-72	(15°) : $\frac{.0417 \times 10.0}{2}$	.21	
7	70-86	1"φ TUBE DIAG. $(\frac{44}{2})$	.22	
9	70-88	1"φ TUBE DIAG.: $(\frac{.44}{2})$	.22	
	70	⟶		2.85
5	72-70	(15°); $\frac{.0417 \times 10.0}{2}$ =	.21	
6	72-74	(20.3°); $\frac{20.3}{360} = .056$		
		$\frac{.056 \times 10.0}{2}$	.28	
	72	⟶		.49
6	74-72	(20.3°); $\frac{.056 \times 10.0}{2}$	.28	
47	74-172	(24.7°); $\frac{24.7}{360}$ =		

No.	TIE		W_{LBS}	ΣW_{LBS}
6	74-72	(20.3°); $\frac{.056 \times 10.0}{2}$	.28	
47	74-172	(24.7); $\frac{24.7}{360} = .069$		
		$\frac{.069 \times 10.0}{2}$ =	.35	
	74	⟶		.63
47	172-74	(24.7°); $\frac{.069 \times 10.0}{2}$ =	.35	
8	172-86	1"φ TUBE DIAG. $\frac{.44}{2}$	.22	
46	172-96	1"φ TUBE DIAGL. $\frac{.44}{2}$	.22	
		2" TUBE FITTG. (DOUBLE)	1.37	
17	172-76	(45°); $\frac{45}{360} = .125$; $\frac{.125 \times 10.0}{2}$ =	.63	
	172	⟶		2.79
17	76-172	(45°) $\frac{.125 \times 10.0}{2}$	.63	
18	76-78	(15°); $\frac{.0417 \times 10.0}{2}$	.21	
	76	⟶		.84
18	78-76	(15°) $\frac{.0417 \times 10.0}{2}$	.21	
19	78-80	(60°) $\frac{.166 \times 10.0}{2}$	.83	
		2" TUBE FITTING (DOUBLE)	1.37	
45	78-96	1"φ TUBE DIAGL. $\frac{.44}{2}$	.22	
44	78-94	1"φ TUBE DIAGL. $\frac{.44}{2}$	.22	
	78	⟶		2.85

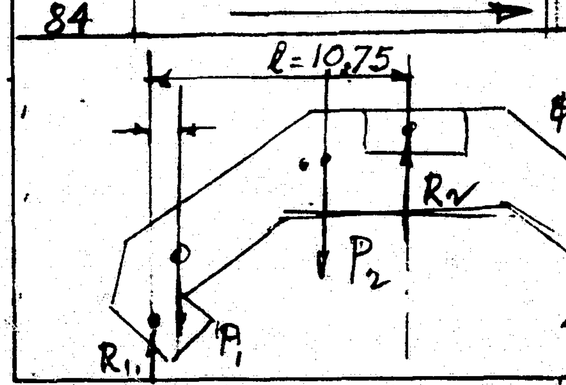
CLASSIFICATION

PREPARED BY	DATE		REPORT NO.
F H BONWIT	6-13-68	JET PROPULSION LABORATORY	
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

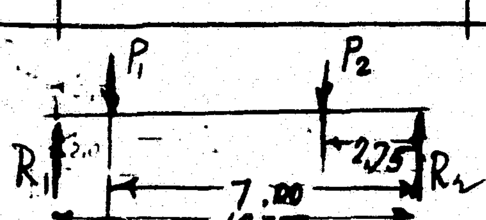
TITLE
WEIGHT ANALYSIS - HOUSING TRUSS - ATM

TIE		W_{LBS}	ΣW_{LBS}
(19) 80-18	60°; $\frac{.166 \times 10.0}{2}$	.83	
(43) 80-94	1"φ TUBE DIAGL. $\frac{.44}{2}$	.22	
(42) 80-92	1"φ TUBE DIAGL $\frac{.44}{2}$	.22	
	2" TUBE FITTG (DOUBLE)	1.37	
(20) 80-82	(15°); $\frac{.0417 \times 10.0}{2}$	.21	
80	⟶		2.85
(20) 82-80	(15°); $\frac{.0417 \times 10.0}{2}$	.21	
(21) 82-354	(15°) $\frac{.0417 \times 10.0}{2}$	.21	
82	⟶		.42
(21) 354-82	(15°) $\frac{.0417 \times 10.0}{2}$	.21	
(41) 354-92	1"φ TUBE SPAR $\frac{.426}{2}$	22,	
(218) 354-84	(6.3°) $\frac{6.3}{360} = .0175$; $\frac{.0175}{2} =$	.09	
	1" TUBE FITTING (SINGLE)	1.25	
354	⟶		1.77
(218) 84-354	(6.3°) $\frac{.0175}{2} =$	.09	
(22) 84-170	(23.7°); $\frac{23.7}{360} = .066$; $\frac{.066 \times 10.0}{2}$	.33	
84	⟶		.42

TIE		W_{LBS}	ΣW_{LBS}
(22) 170-84	(23.7°) $\frac{.066 \times 10.0}{2}$	.33	
(23) 170-352	(30°); $\frac{30}{360} = .083$; $\frac{.083 \times 10.0}{2} =$	.42	
170	⟶		.75
(217) 352-60	(15°) $\frac{.0417}{2} \times \frac{10.0}{2}$	.21	
(40) 352-90	1"φ TUBE SPAR $\frac{.426}{2}$	.22	
(23) 352-170	(30°); $\frac{.083 \times 10.0}{2}$	.42	
	1" TUBE FITTG. (SINGLE)	1.25	
352			2.10
	WT. OF 1"φ TUBE RING = 3.73#		
(129) 96-182	(30°); $\frac{.083 \times 3.73}{2} =$	.15	
(46) 96-172	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
	1" TUBE FITTING (DOUBLE)	1.32	
(45) 96-78	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
(49) 96-94	(60°); $\frac{.166 \times 3.73}{2}$	.31	
(64) 96-106	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
	1" TUBE FITTG. (DOUBLE)	1.32	
(63) 96-104	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
(134) 96-178	(PIVOT YOKE ETC.)	9.92	
96	⟶		14.14



PIVOT YOKE & PIVOT PARTS
25.76
W_1 33% = 8.56*
66% = 17.00
W_2



$P_1 = 8.56$ 33%
$P_2 = 17.00$ 66%
ΣP 25.56

$$R_1 = \frac{P_2 \times 2.75 + P_1 7.00}{10.75} = \frac{(17.0 \times 2.75) + (8.56 \times 7.00)}{10.75} = 9.92$$

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT — PREPARED BY — 6-14-68 DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO. ______
CHECKED BY ______ DATE ______ PROJECT ______

TITLE: WEIGHT ANALYSIS - HOUSING TRUSS - ATM

No.	TIE		W_{LBS}	ΣW_{LBS}
40	94-96	(60°) $\frac{.166 \times 3.73}{2}$	.31	
44	94-78	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
		1" TUBE FITTG. (DOUBLE)	1.32	
43	94-80	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
50	94-92	(60°) $\frac{.166 \times 3.73}{2}$	.31	
62	94-104	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
		1" TUBE FITTG (DOUBLE)	1.32	
61	94-102	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
	94	⟶	4.38	4.38
50	92-94	(60°) $\frac{.166 \times 3.73}{2}$	.31	
42	92-80	1" TUBE DIAGL $\frac{.44}{2}$	.22	
		1" TUBE FITTG. (DOUBLE)	1.32	
41	92-354	1" TUBE SPAR $\frac{.426}{2}$	.22	
51	92-248	(30°) $\frac{.083 \times 3.73}{2} + \frac{1.26}{4}$	.48	
60	92-102	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
		1" TUBE FITTG. (DOUBLE)	1.32	
59	92-100	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
	92	⟶		4.55
51	240-92	(30°) $\frac{.083 \times 3.73}{2}$	.15	
134	240-90	(30°) $\frac{.083 \times 3.73}{2}$	.15	
		MIRROR SUPPT. YOKE $\frac{1.26}{2}$	.63	
	240	⟶		.73

No.	TIE			
	248	⟶	.15	.15
	250	HEAT DUMP MIRROR ⟶		1.91
134	90-240	(30°) $\frac{.083 \times 3.73}{2} + \frac{1.26}{4}$	.48	
40	90-352	1" TUBE SPAR $\frac{.426}{2}$	.22	
39	90-68	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
		1" TUBE FITTG. (DOUBLE)	1.32	
58	90-100	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
		1" TUBE FITTG. (DOUBLE)	1.32	
57	90-110	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
52	90-88	(60°) $\frac{.166 \times 3.73}{2}$	.31	
	90	⟶		4.55
52	88-90	(60°) $\frac{.166 \times 3.73}{2}$	.31	
10	88-68	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
		1" TUBE FITTG. (DOUBLE)	1.32	
9	88-70	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
56	88-110	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
		1" TUBE FITTG (DOUBLE)	1.32	
55	88-108	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
10	88-86	(60°) $\frac{.166 \times 3.73}{2}$	.31	
	88	⟶		4.38

CLASSIFICATION

JPL 0999-1-5 APR 66

PAGE WA-6 OF ____

F.H. BON[illegible]IT — PREPARED BY | 6-14-68 — DATE | **JET PROPULSION LABORATORY** | REPORT NO.

CHECKED BY | DATE | **CALIFORNIA INSTITUTE OF TECHNOLOGY** | PROJECT

TITLE

TIE		W_{LBS}	ΣW_{LBS}
(10) 86-88	(60°) $\frac{.166 \times 3.73}{2}$	.31	
(7) 86-70	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
	1" TUBE FITTG. (DOUBLE)	1.32	
(8) 86-172	1" TUBE DIAGL. $\frac{.44}{2}$	.22	
(53) 86-106	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
	1" TUBE FITTG. (DOUBLE)	1.32	
(54) 86-108	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
(48) 86-182	(30°) $\frac{.083 \times 3.73}{2}$	.15	
86-178	(PIVOT YOKE ETC.)	9.92	
86	$\longrightarrow$		14.14
(48) 182-86	(30°) $\frac{.0833 \times 3.73}{2}$	.15	
(120) 182-96	(30°) $\frac{.0833 \times 3.73}{2}$	.15	
182	$\longrightarrow$		.30
(70) 100-102	(60°) $\frac{.166 \times 3.73}{2}$	.31	
(65) 100-110	(60°) $\frac{.166 \times 3.73}{2}$	.31	
	1" TUBE FITTG. (DOUBLE)	1.32	
(57) 100-92	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
(71) 100-114	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
(58) 100-96	1" TUBE DIAGL. $\frac{.673}{2}$	.34	
	1" TUBE FITTG. (DOUBLE)	1.32	
(82) 100-124	1 TUBE DIAGL. $\frac{.673}{2}$	.34	
100			4.62

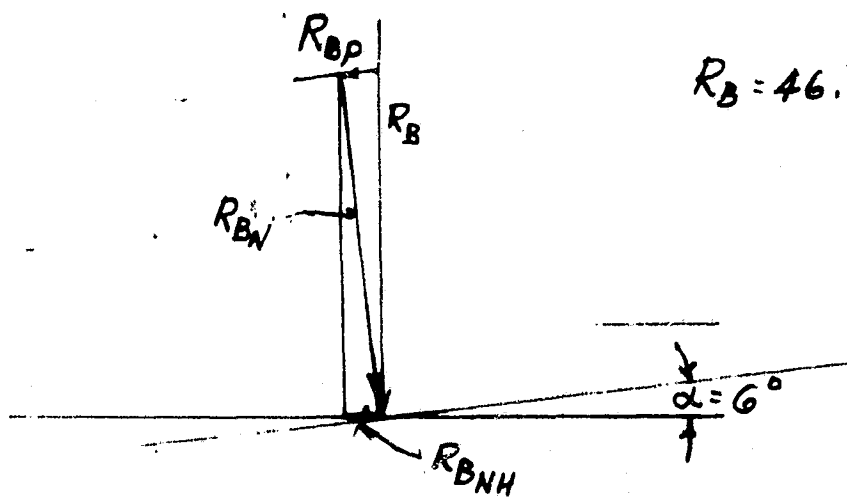
CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT	6-7-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE

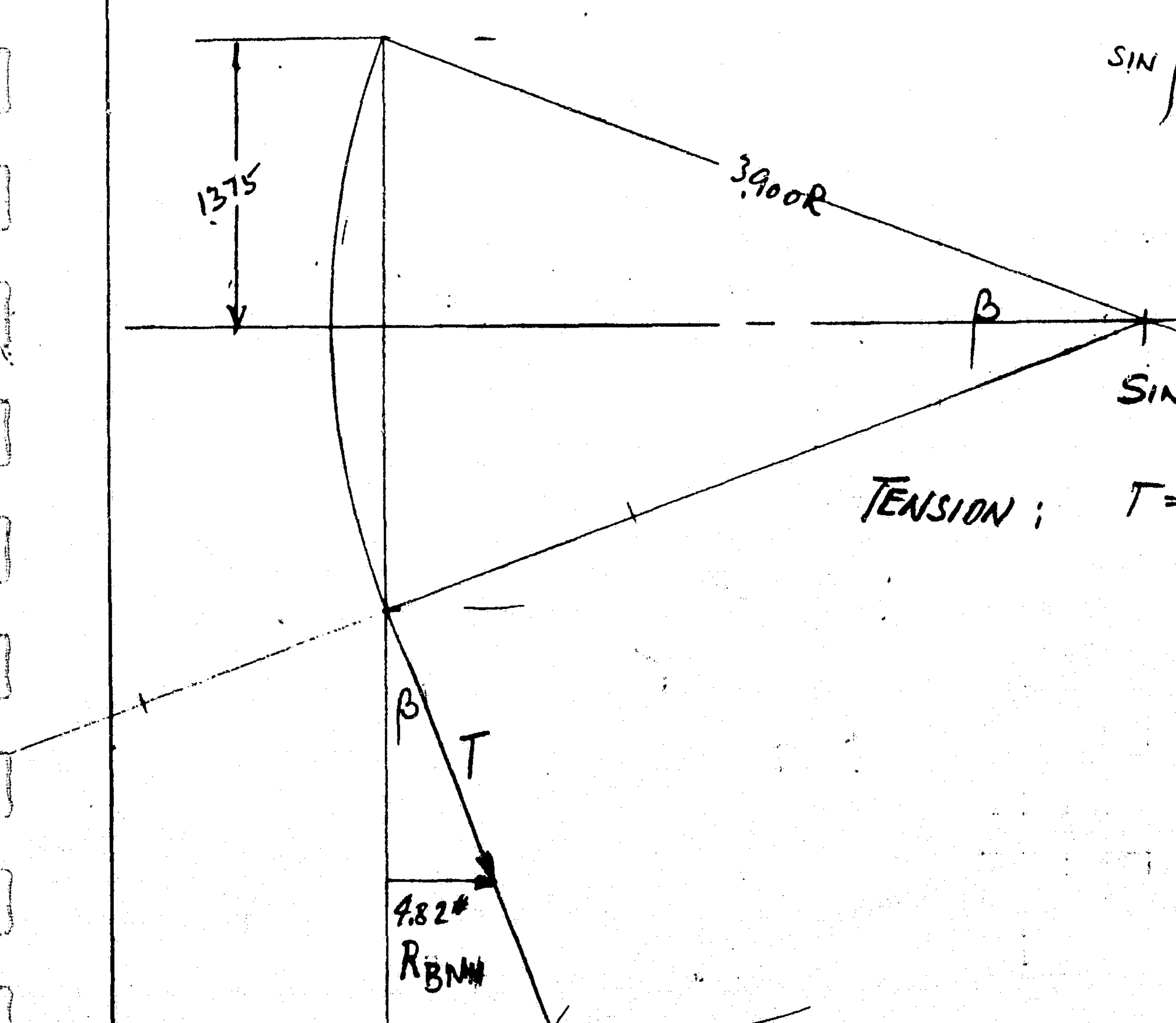
STRESS ANALYSIS – MOUNTING OF PRIMARY MIRROR (CONT'D)



$R_B = 46.37\ LBS$; $R_{BN} = R_B \cos\alpha$

$R_{BNH} = R_{BN} \sin\alpha = R_B \sin\alpha \times \cos\alpha$

$R_{BNH} = 46.37 \times .1045 \times .99452 = 4.82\ LBS$



$\sin\beta = \frac{1.375}{3.900} = .353$

$\alpha = 20.7$

$R_{BHN} = 4.82\ LBS$

$\sin\beta = \frac{R_{BNH}}{T}$; $T = \frac{R_{BNH}}{\sin\beta}$

TENSION ; $T = \frac{4.82}{.353} = 13.65\#$

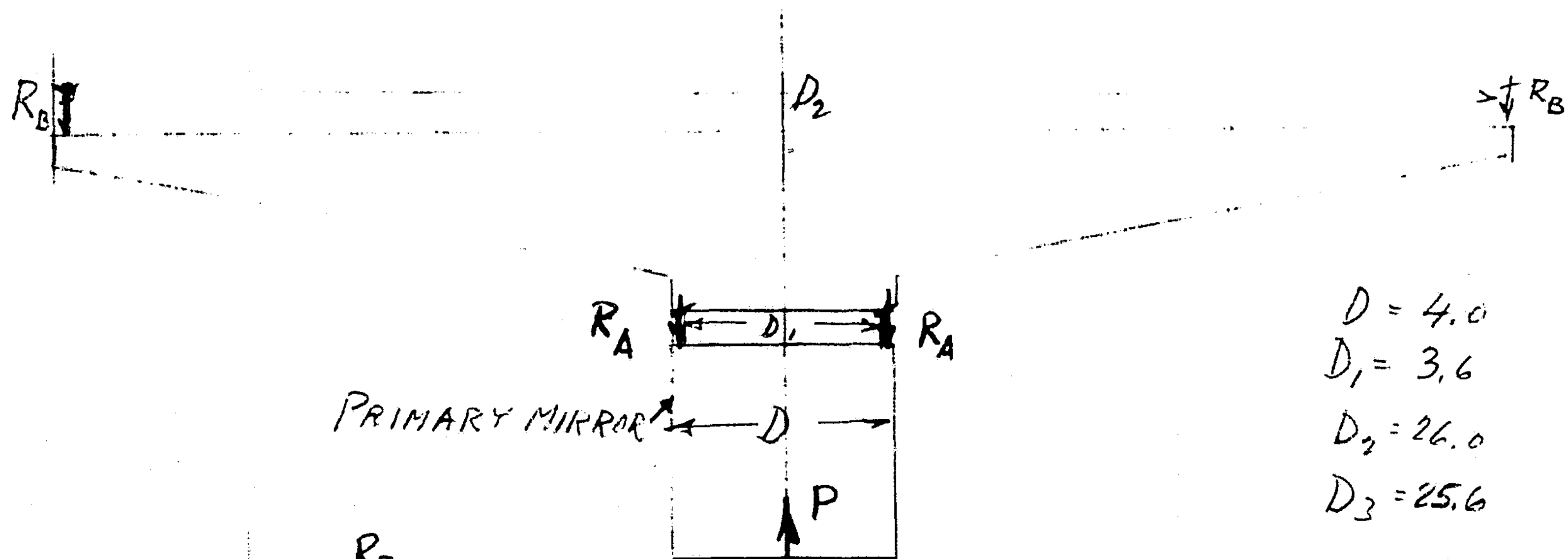
CLASSIFICATION

JPL 0999-1-S APR 66

F.H. Brennwit	6-6-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE

STRESS ANALYSIS - MOUNTING OF PRIMARY MIRROR

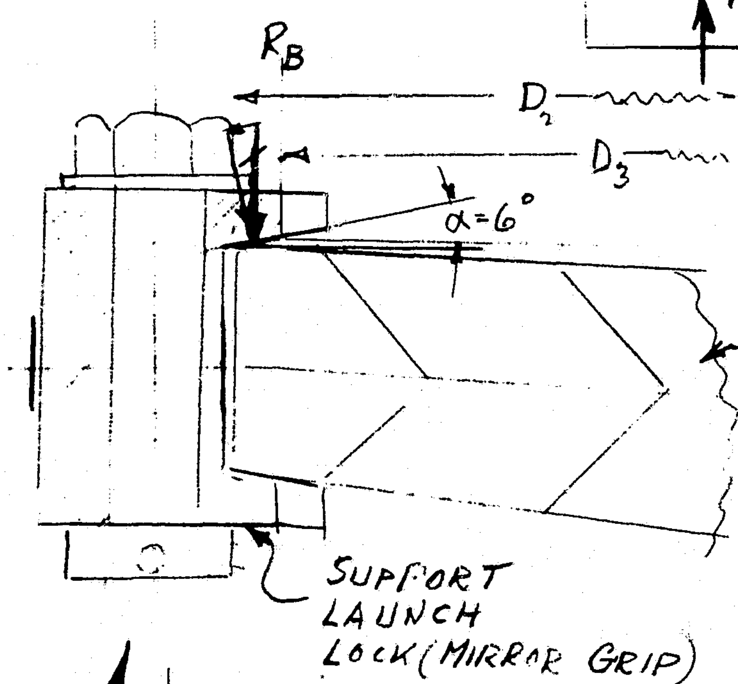


$D = 4.0$

$D_1 = 3.6$

$D_2 = 26.0$

$D_3 = 25.6$



MIRROR RETAINED BY (2) ANNULAR AREAS:

@ SPLIT RING OF MOUNTING CELL BRACKET) $A_A = (D^2 - D_1^2) \times .785 =$

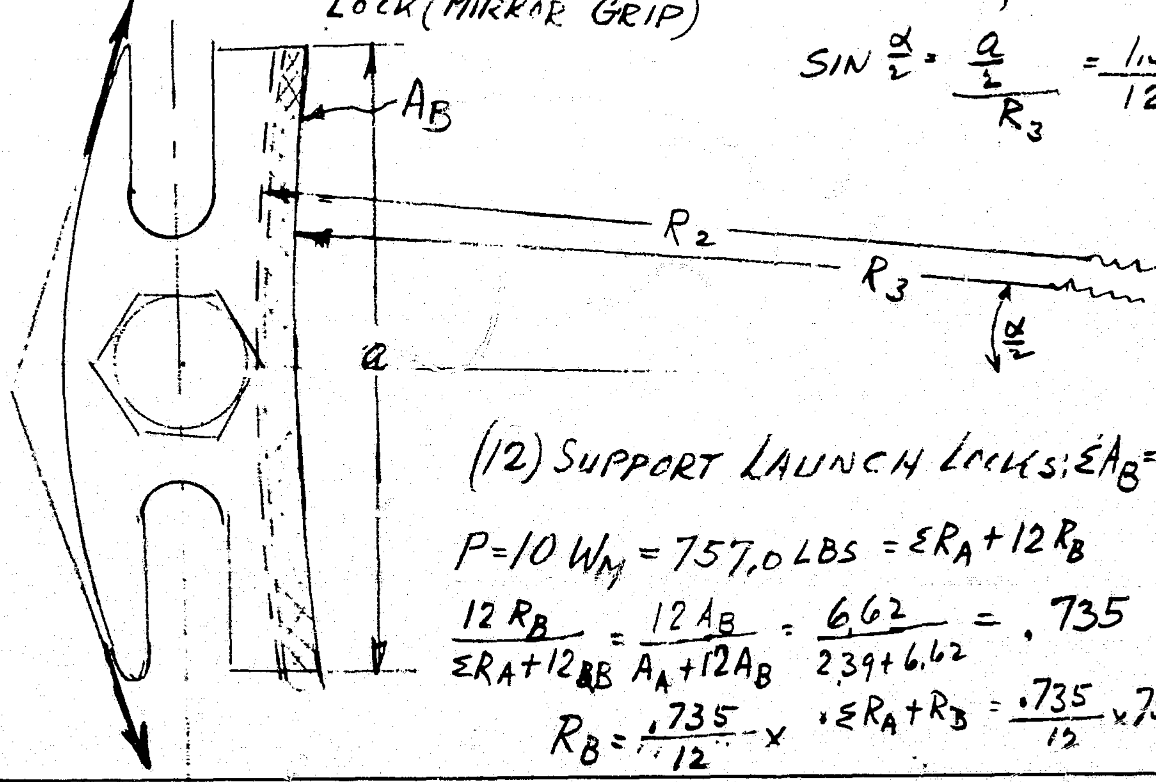
$\underline{A_A = (4.0^2 - 3.6^2).785 = \underline{2.39\ IN^2}}$

@ (12) MIRROR GRIPS OF SUPPORT LAUNCH LOCK;

$a = 2.75,\ R_2 = \frac{D_2}{2} = 13.0;\ \ R_3 = 12.8$

$\sin\frac{\alpha}{2} = \frac{\frac{a}{2}}{R_3} = \frac{1.375}{12.8} = .1075,\ \frac{\alpha}{2} = 6.12°$

$\alpha = 12.24°$



$A_B = \frac{12.24}{360}(R_2^2 - R_3^2)\pi =$

$= .551\ IN^2$ 5.16

(12) SUPPORT LAUNCH LOCKS: $\Sigma A_B = \underline{12(A_B)} = 12 \times .551 = \underline{6.62\ IN^2}$

$P = 10\ W_M = 757.0\ LBS = \Sigma R_A + 12 R_B$ (WEIGHT OF MIRROR) $W_M = 75.7\ LBS$

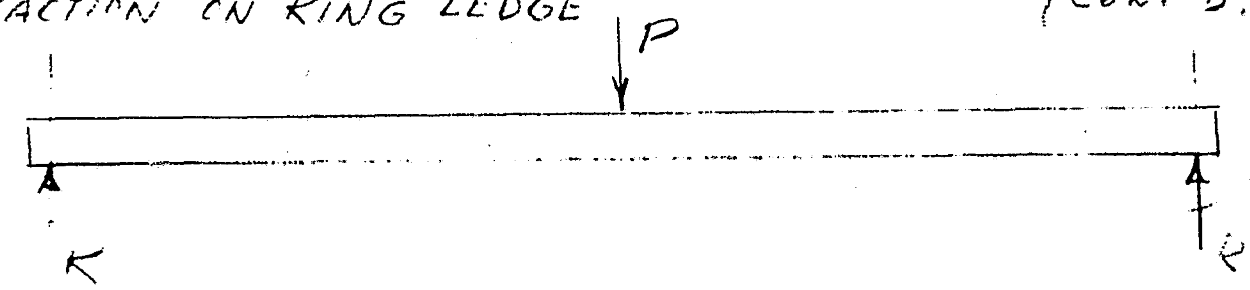
$\frac{12 R_B}{\Sigma R_A + 12 R_B} = \frac{12 A_B}{A_A + 12 A_B} = \frac{6.62}{2.39 + 6.62} = .735$ $R_A = .265 \times 757.0 = 200.6^{\#}$

$R_B = \frac{.735}{12} \times \Sigma R_A + R_B = \frac{.735}{12} \times 757.0 = 46.37\ LBS$

F. H. Bonwit PREPARED BY	6-6-68 DATE	JET PROPULSION LABORATORY	REPORT NO.
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

TITLE STRESS ANALYSIS BASE MOUNTING RING (PRIMARY MIRROR)

REACTION ON RING LEDGE (CONT'D.)



ASSUME 10 G's

$P = 1{,}166.4$ LBS

$R = \frac{P}{2} = \frac{1{,}166.4 \text{ LBS}}{2} = 583.2$ LBS – TO BE DISTRIBUTED OVER

(3) TRUSS "FACES" EACH: $A_T = 1.0 \times .6 = .6 \text{ IN}^2$

$f_c = \frac{R}{3A_T} = \frac{583.2}{3 \times .6} = \underline{324.0 \text{ PSI}}$

FOR INVAR: $F_c = 40{,}000$ PSI

$M.S. = \frac{F}{f} - 1 = \frac{40{,}000}{324} - 1 = \underline{HIGH}$

CLASSIFICATION

JPL 0999-1-S APR 66

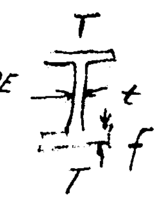
H. BONWIT PREPARED BY · 6-5-68 DATE · JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY · REPORT NO. ____

CHECKED BY ____ DATE ____ PROJECT ____

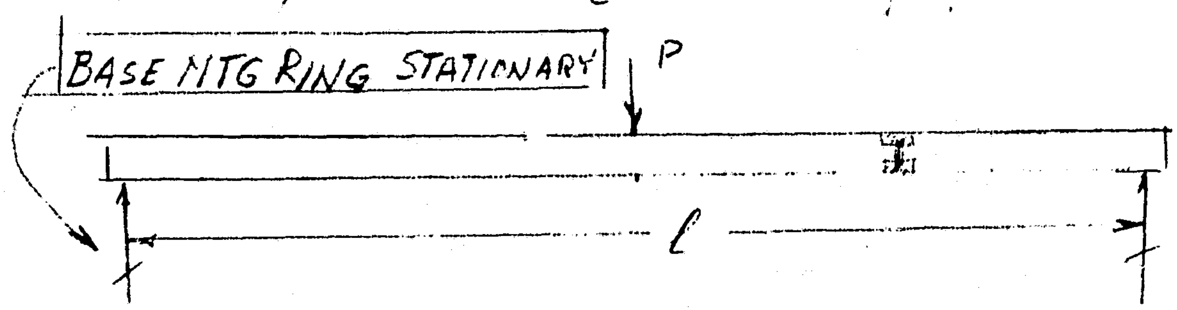
TITLE STRESS ANALYSIS — BASE MOUNTING RING — PRIMARY MIRROR

DEFLECTION:

ASSUME: PAIR OF "TRUSSES" OF BASE MOUNTING RING TO ACT LIKE "SIMPLE BEAM" WITH REACTIONS ON RING LEDGE. — TRUSS TO HAVE "MEAN HIGHT" $h = \frac{1.85+5.0}{2} = \frac{6.85}{2} \approx 3.43$; I BEAM-SHAPE



$T = 1.0$; $t = .063$ $\ell = 28.0$ $f = .125$



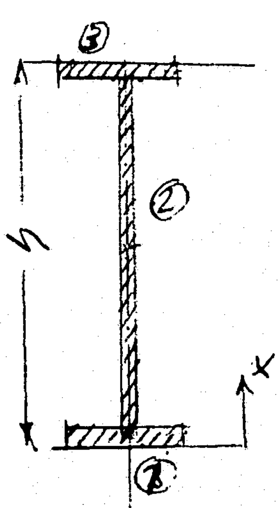
ASSUME: 10 G's

$W_{M(MIRROR)} = 75.7$ LBS

$P = \Sigma W \times 10 = 116.64 \times 10 = 1,166.4$ LBS $\Sigma W = W_{TRUSS\,PAIR} + W_{BASE\,MTG.\,CELL\,BRACKET} + W_M$

$W_T = 6.74$ LBS ; $W_B = 34.2$ LBS $\Sigma W = W_T + W_B + W_M = 6.74 + 34.2 + 75.7 = 116.64$

$E = 21.0 \times 10^6$ (INVAR "36")



ITEM	AREA	A	d	Ad	Ad²	I_o
1	1.0×.125	.125	.063	.008	.0005	—
2	3.18×.063	.20	1.715	.343	.588	.169
3	1.0×.125	.125	3.367	.421	1.418	—
		.450		.772	2.0065	ΣI_o .169

$\bar{X} = \frac{\Sigma Ad}{\Sigma A} = \frac{.772}{.450} = 1.715''$ $\bar{X}^2 = 2.94\,IN^2$

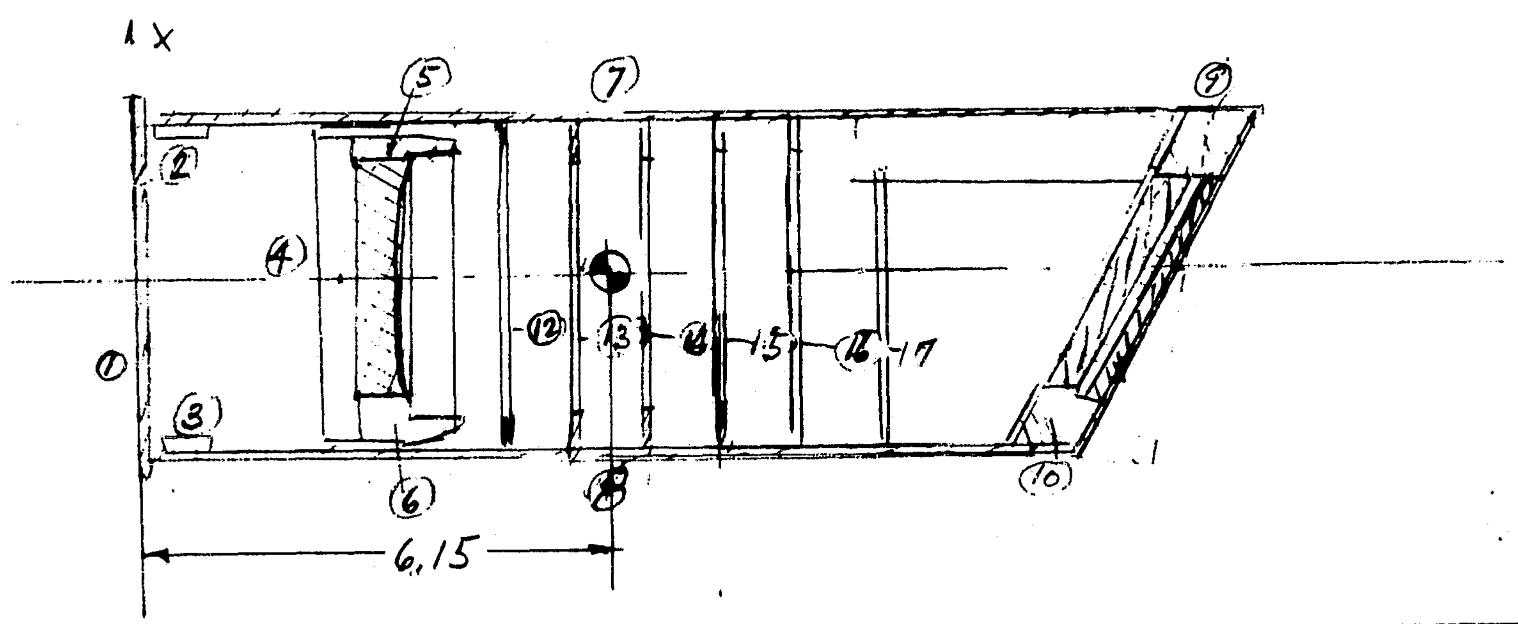
$I = \Sigma I_o + Ad^2 - \Sigma A\bar{X}^2 = .169 + 2.0065 - .450 \times 2.94 = \underline{.855\,IN^4}$

$\Delta_x = \frac{P\ell^3}{48EI} = \frac{1,166.40 \times 21,952}{48 \times 21.0 \times 10^6 \times .855} = .0297$ IN DEFLECTION, IF ONLY ONE PAIR OF TRUSSES IS USED, SINCE, HOWEVER, (3) PAIRS OF TRUSSES ARE USED FOR SUPPORT $\frac{\Delta_x}{3} = \underline{.0099\,IN}$ IS MORE REALISTIC DEFLECTION

F H BONLAIT	6-4-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE C. G. CALC. – SECONDARY MIRROR ASSY.

SEE PAGES 13, 14 & 15



	AREA	A	d	Ad
1	Dt = 5.0 × .25	1.25	.13	1.63
2	.5 × .1	.05	.5	.025
3	.5 × .1	.05	.5	.025
4	4.0 × .5	2.0	2.7	5.4
5	1.0 × .5	.5	3.3	1.66
6	1.0 × .5	.5	3.3	1.66
7	14.5 × .1	1.45	7.5	10.85
8	11.7 × .1	1.17	6.1	7.14
9	1.0 × .7	.7	14.0	9.8
10	1.0 × .7	.7	11.7	8.2
12	2(.55 × .1)	.11	4.7	.52
13	2(.55 × .1)	.11	5.6	.62
14	2(.55 × .1)	.11	6.6	.73
15	2(.55 × .1)	.11	7.6	.84
16	2(.55 × .1)	.11	8.6	.95
17	2(.55 × .1)	.11	9.6	1.06
	ΣA	9.03	Σ	51.12

$$\bar{d} = \frac{\Sigma Ad}{\Sigma A} = \frac{51.12}{9.03} = 5.68$$

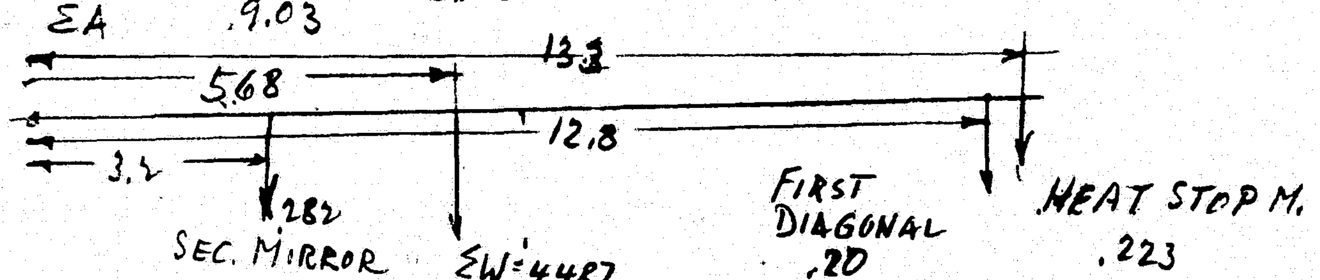
$\Sigma W_{AL} =$ 3.03
.093
1.06
.054
.25
4.487 LBS

4.487 ΣW_{AL}
+ .20 FIRST DIAG.
.223 HEAT STOP MIRROR
.282 SECONDARY MIRROR
$\Sigma W = 5.192$ LBS

$$\Sigma M = (3.2 \times .282) + \bar{d}\,\Sigma W_{AL} + (12.8 \times .20) + (13.3 \times .223) = d_x \times \Sigma W$$

$$= (3.2 \times .282) + (5.68 \times 4.487) + (12.8 \times .20) + (13.3 \times .223) = d_x \times 5.192$$

$$= \frac{.9 + 25.5 + 2.56 + 2.96}{5.192} = \frac{31.92}{5.192} = \underline{6.147}$$



CLASSIFICATION

JPL 0999-1-S APR 66

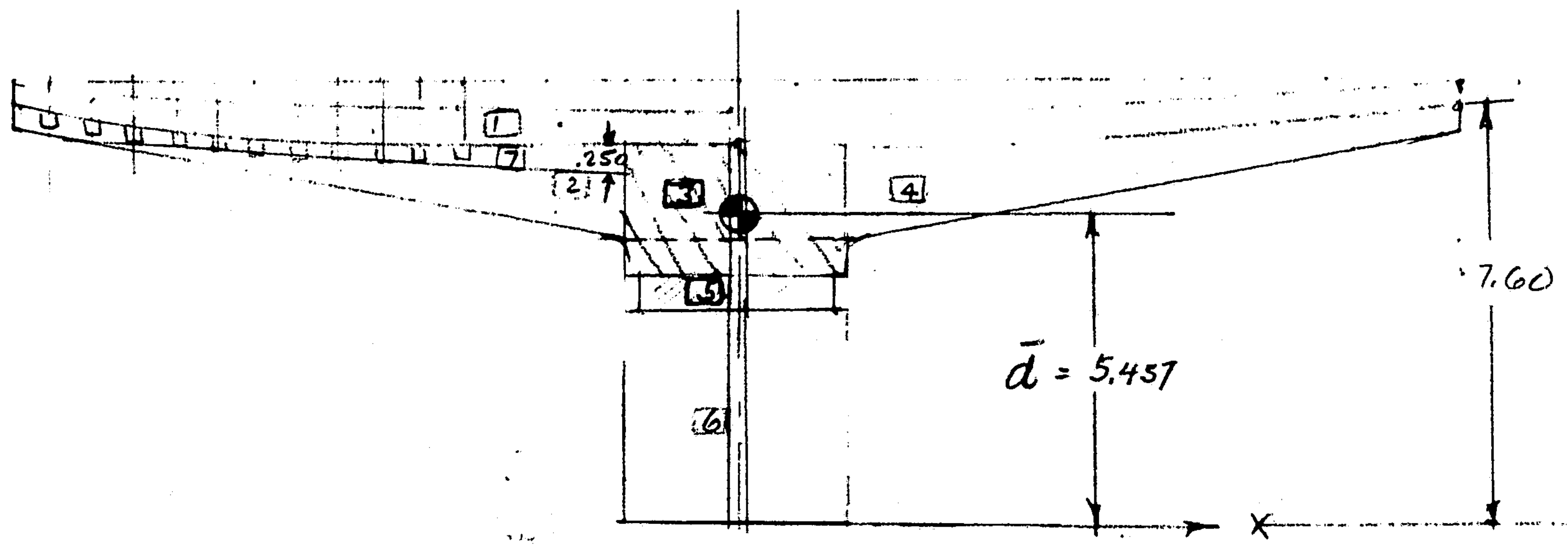
F. H. Bonnit — PREPARED BY — 5-22-68 DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO.

CHECKED BY — DATE — PROJECT

TITLE C. G. CALC. – PRIMARY MIRROR



	AREA	A	d	Ad
1	26.25 × .5	13.10	7.25	95.00
2	11 × 1.85 × .5	10.20	6.40	65.30
3	2.25 × 3.75	8.40	5.80	48.80
4	11.0 × 1.85 × .5	10.20	6.40	65.30
5	.625 · 3.35	2.09	4.30	9.00
6	3.975 × 3.75	14.85	2.00	29.70
7	[(28).5 + 4.85] .25 (18.85)	4.71	7.00	33.70
		Σ 63.55		Σ 346.80

$$\bar{d} = \frac{\Sigma Ad}{\Sigma A} = \frac{346.80}{63.55} = 5.457$$

CLASSIFICATION

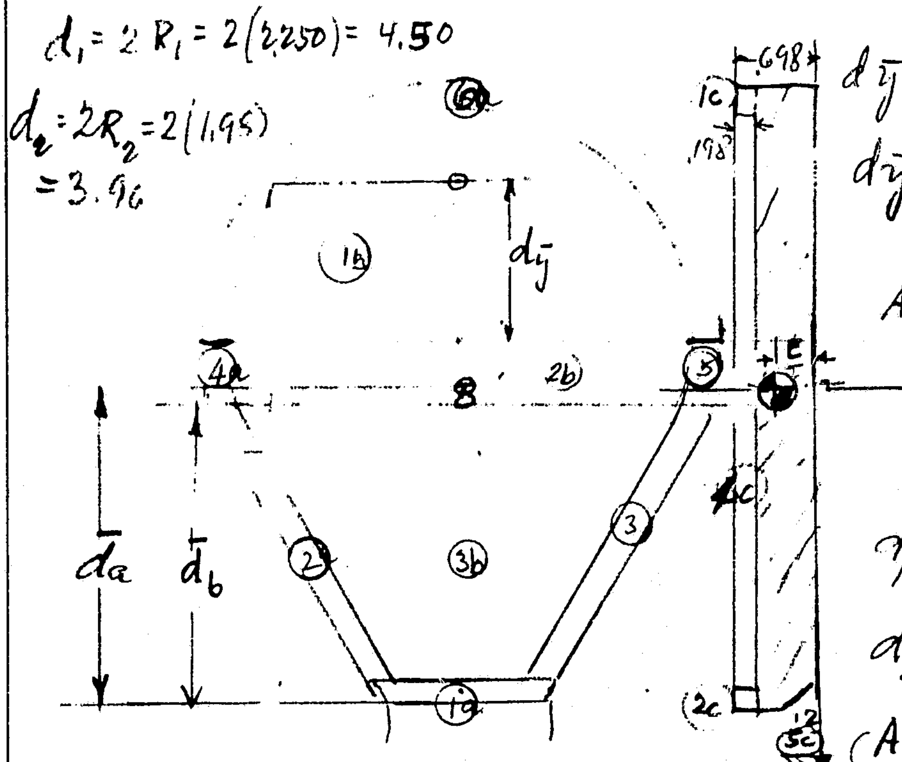
JPL 0999-1-S APR 66

F. H. BONWIT	5-14-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE CENTER OF GRAVITY CALC. – 2ND DIAGONAL MIRROR ASSY, REF. DWG. 10026213

$d_1 = 2R_1 = 2(2.250) = 4.50$

$d_2 = 2R_2 = 2(1.98) = 3.96$



$$d\bar{y} = \frac{2(d_1^3 - d_2^3)}{3\pi(d_1^2 - d_2^2)} = \frac{2(4.5^3 - 3.96^3)}{3\pi(4.5^2 - 3.96^2)} = \frac{2(91.25 - 62.0)}{3\pi(20.25 - 15.7)}$$

$$d\bar{y}_a = \frac{58.50}{42.80} = 1.365; \quad a + d\bar{y} = 3.100 + 1.365$$

$d\bar{y} = 4.465$

$A_⑥ = .3927(d_1^2 - d_2^2) = .3927 \times 4.55 = 1.785\ IN^2$

$\bar{y}_b = .288\, d_1 = .288 \times 4.50 = 1.295$

$\bar{d}_{1b} = (a + R_1) - \bar{y}_b = 3.100 + 2.250 - 1.295 = 4.055$

$$d_{3b} = \frac{d(4R_1 + 2K)}{3(2R_1 + 2K)} = \frac{2.6(9.0 + 1.616)}{3(4.5 + 1.616)} = 1.5$$

$$A_{3b} = \frac{d(2R_1 + 2K)}{2} = \frac{2.6(4.5 + 1.616)}{2} = 7.95$$

	AREA	A	d	Ad
1a	1.616 × .138	.222	.069	.015
2a	2.80 × .270	.756	1.25	.947
3a	2.80 × .270	.756	1.25	.947
4a	.5 × .270	.135	3.0	.405
5a	.5 × .270	.135	3.0	.405
6a	.3927 × 4.55	1.785	4.465	7.990
	ΣA	3.789	ΣAd	10.709

$$\bar{d}_a = \frac{\Sigma Ad}{\Sigma A} = \frac{10.709}{3.789} = 2.83$$

	AREA	A_b	d_b	Ad_b
1b	$.3927 d_1^2$ =	7.95	4.055	32.30
2b	2.0 × .5	1.0	2.85	2.85
3b		7.95	1.5	11.95
	ΣA_b =	16.90	ΣAd	47.10

$$\bar{d}_b = \frac{\Sigma Ad_b}{\Sigma A_b} = \frac{47.10}{16.90} = 2.79$$

ab	AREA	A_{ab}	d_{ab}	Ad_{ab}
1		3.789	2.83	10.7
2		16.90	2.79	47.2
		20.689		57.9

$\frac{.098}{.178} = 55\%$

$\frac{.08}{.178} = 45\%$

$$\bar{d}_{ab} = \frac{57.9}{20.689} = 2.8$$

	AREA	A	c	Ac
1c	.270 × .198	.054	.599	.032
2c	.138 × .198	.027	.599	.017
3c	.5 × 5.350	2.675	.25	.667
4c		2.756		.716

$$\bar{c} = \frac{\Sigma Ac}{\Sigma A} = \frac{.716}{2.756} = .26$$

a+c		A
1	.55 × 2.756	1.512
2	.45 × .276 × 4.919	

CLASSIFICATION

JPL 0999-1-S APR 66

F. A. E[illegible]NIT — PREPARED BY | 5-31-68 — DATE | JET PROPULSION LABORATORY | REPORT NO.

CHECKED BY | DATE | CALIFORNIA INSTITUTE OF TECHNOLOGY | PROJECT

TITLE WEIGHT CALC. - INDEX & GRAND SUMMARY

ITEMS	SUMMARY PAGE	"A" DENOTES ITEM OR PAGE REVISED FOR LATEST DESIGN	LBS	
1pm	1	PRIMARY MIRROR	75.7	302,12
2m - 6m	5A	MOUNTING CELL [illegible]	34.22	
1b	7A	BASE MOUNTING RING	113.00	
1s-8s	12A	SUPPORT LAUNCH LOCK	79.20	
1a-12a	15	SECONDARY MIRROR ASSY.	80.41	
1d-9d	19	2ND DIAGONAL MIRROR ASSY.	5.30	
1tp-6tp 1tf-4tf	26	HOUSING TRUSS SUSPENSION	165.53	
1t-4t	28	HOUSING TRUSS (TUBULAR) INCL. TUBE FITTINGS	157.72	
1e-5e	31	ELECTRICAL & ELECTRONICS	64.0	
1c-8c	32	CAMERA, VIDICON CLUSTER & RACK	76.5	
1w-4w	35	HEAT DUMP MIRROR SYSTEM	4.14	

GRAND TOTAL: 855.72

NOTE:
NO "CONTINGENCIES" ESTABLISHED

PAGES: 2, 6, 21 & 23 ELIMINATED

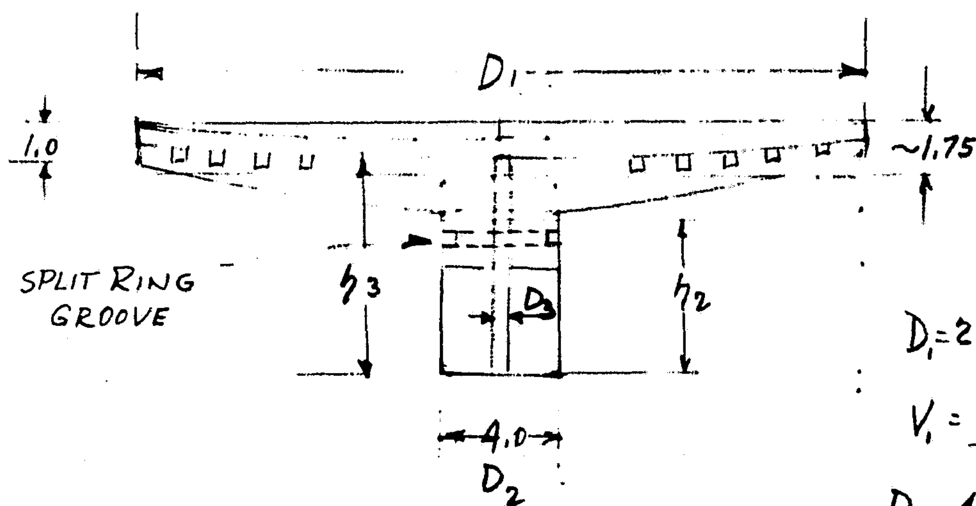
CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT	4-30-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	REPORT NO.
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC. - PRIMARY MIRROR

1pc. MIRROR (ULTRA LOW EXP.)



MATL.: U.L.E FUSED SILICA #7971 (CORNING GLASS WKS)

DENSITY: $2.21\ gr/cm^3\ (\rho)$

OR: $2.21 \times .0361 = .08\ \#/IN^3$

$h_1 = \frac{1+2.5}{2} = 1.75$

	IN^3
$D_1 = 26.00$	
$V_1 = D_1^2 \times .785 \times h_1 = (26.0)^2 \times .785 \times 1.75 =$	930
$D_2 = 4.0 \quad h_2 = 5.0$	
$V_2 = D_2^2 \times .785 \times h_2 = (4.0)^2 \times .785 \times 5.0 =$	62.8
	992.8
SUBTRACT COOLING GROOVES: $L = \sim 60.0 = 720$	
$(-)\ V_3 = .25 \times .25 \times L = .0625 \times 720 =$	-44.9
" COOLING BORE:	
$D_3 = .25\ ;\ h_3 = 7.125$	
$(-)\ V_4 = D_3^2 \times .785 \times h_3 = (.25)^2 \times .785 \times 7.125 =$	-.3
" ANNULAR SPLIT RING GROOVE:	
$D_2 = 4.0\ ;\ d_2 = 3.60 \quad h_4 = .625$	
$(-)\ V_5 = .785(D_2^2 - d_2^2) \times h_4 = .785(4^2 - 3.6^2) \times .625 =$	-1.49
$\Sigma V =$	946.11

$W = \Sigma V \times \rho = 946.11 \times .08 = \underline{75.7\ LBS}$

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BONWIT	5-15-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	REPORT NO.
CHECKED BY	DATE		PROJECT

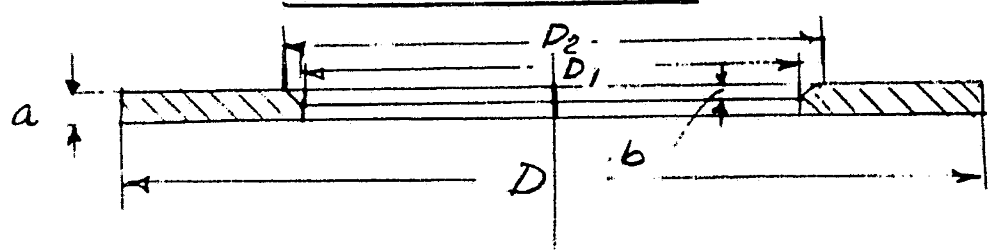
TITLE
WEIGHT CALC. - MOUNTING CELL BRACKET (PRIMARY MIRROR)

2mA

RING CLAMP

MATL.: INVAR "36"

$\rho = .291\ \#/IN^3$



$D = 7.4 \quad a = .3$

$D_1 = 4.3 \quad b = .15$

$D_2 = 4.6$

	IN^3
$V_1 = (D^2 - D_1^2) .785 \times a = (7.4^2 - 4.3^2) .785 \times .3 =$	8.55
(BEVEL) $V_2 = .2618\, b (D_2^2 + D_1 D_2 + D_1^2) = .2618 \times .15 (4.6^2 + 4.3 \times 4.6 + 4.3^2)$	- 2.33
$\Sigma V =$	6.22

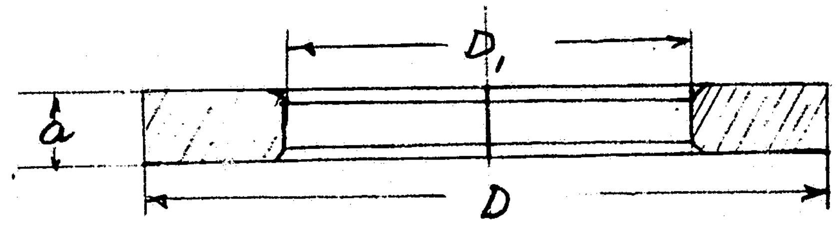
$W = \Sigma V \times \rho = 6.22 \times .291 = \underline{1.815\ LBS}$

3mA

SPLIT RING

MATL.: INVAR "36"

$\rho = .291\ \#/IN^3$



$D = 6.0 \quad a = .6$

$D_1 = 3.6$

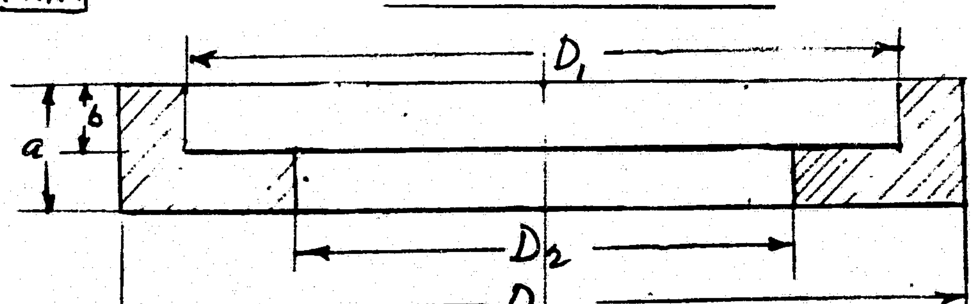
	IN^3
$V_1 = (D^2 - D_1^2) \times .785 \times a = (6.0^2 - 3.6^2) .785 \times .6 =$	10.85
-5% BEVELLING	- .55
$\Sigma V =$	10.30

$W = \Sigma V \times \rho = 10.30 \times .291 = \underline{3.0\ LBS}$

4mA

RING SUPPORT

MATL.: INVAR "36" $\rho = .291\ \#/IN^3$



$D = 7.4;\ D_1 = 6.4;\ D_3 = 4.3$

$a = 1.1;\ b = .6 \quad a - b = .5$

	IN^3
$V_1 = D^2 .785 \times a = 7.4^2 \times .785 \times 1.1$	47.25
$V_2 = D_1^2 \times .785 \times b = 6.4^2 \times .785 \times .6$	- 19.25
$V_3 = D_2^2 \times .785 \times (a-b) = 4.3^2 \times .785 \times .5$	- 7.26
ΣV	20.74

$W = \Sigma V \times \rho = 20.74 \times .291 = \underline{6.03\ LBS}$

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. Schmitt	5-15-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

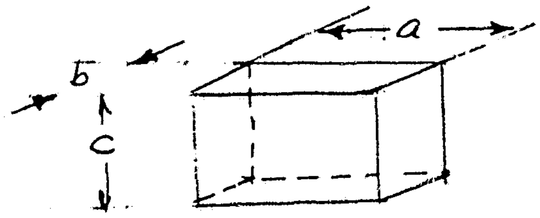
TITLE

WEIGHT CALC. - MOUNTING CELL BRACKET (PRIMARY MIRROR)

5mA CENTERING BLOCK

MATL.: INVAR "36"

$\rho = .291 \#/in^3$



$a = .75;\ b = .3;\ c = .4$

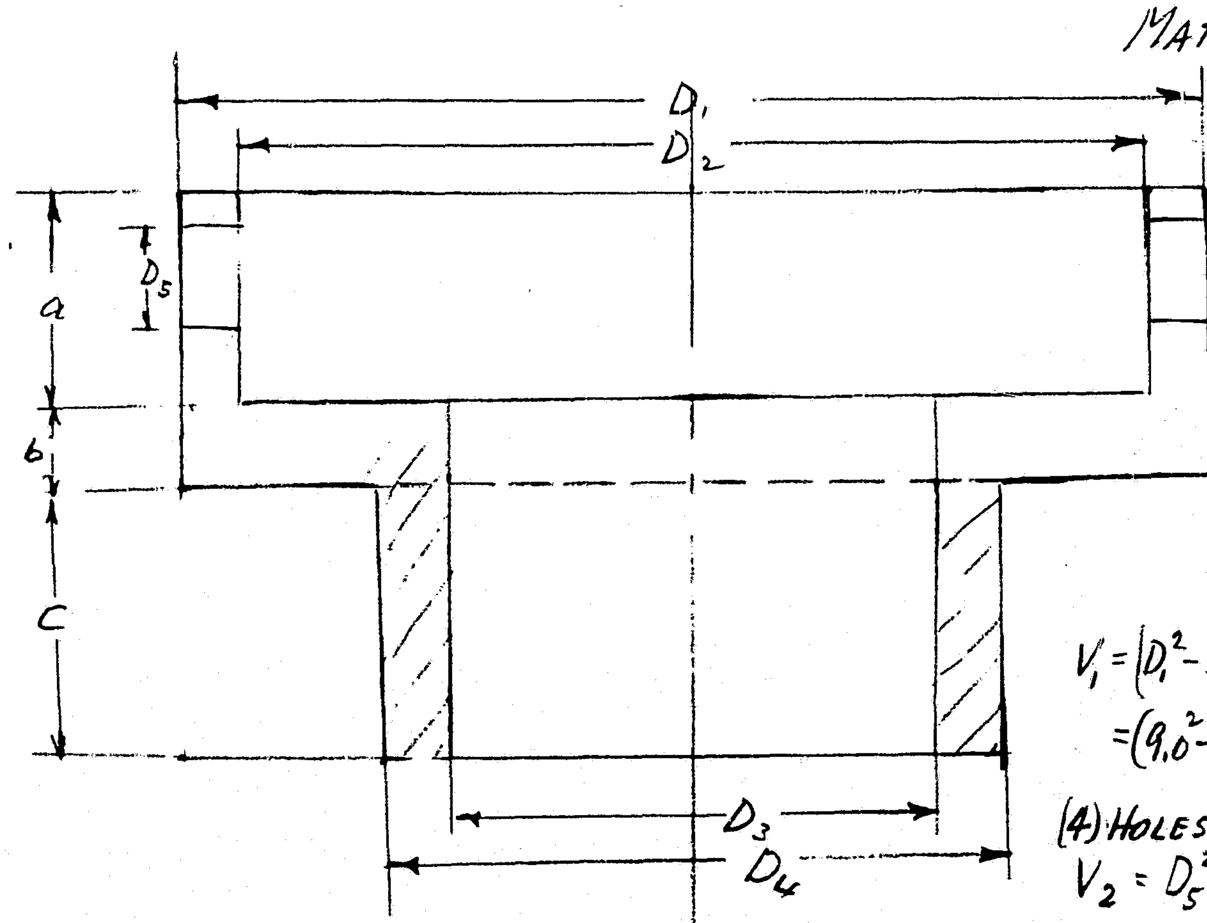
$\Sigma V = a \times b \times c = .75 \times .3 \times .4$ — IN^3: .09

COMBINATION) (3) $W = 3 \Sigma V \times \rho$ $\quad 3 \times .09 \times .291 = \underline{\underline{.0784\ LBS}}$

6mA HUB SUPPORT (ONE PIECE)

MATL.: INVAR "36"

$\rho = .291$



$D_1 = 9.0 \quad a = 1.9$

$D_2 = 8.0 \quad b = .7$

$D_3 = 4.3 \quad c = 2.4$

$D_4 = 5.5$

$D_5 = 1.0$

	IN
$V_1 = (D_1^2 - D_2^2) \times .785 \times a =$ $= (9.0^2 - 8.0^2) \times .785 \times 1.9 =$	25.4
(4) HOLES: $V_2 = D_5^2 \times .785 \times \left(\frac{D_1 - D_2}{2}\right) \times 4$ $= 1.0^2 \times .785 \times \left(\frac{9.0 - 8.0}{2}\right) \times 4 =$	− 1.57
	23.83
$V_3 = (D_1^2 - D_3^2) \times .785 \times b = (9.0^2 - 4.3^2) \times .785 \times .7 =$ (62.51)	34.30
$V_4 = (D_4^2 - D_3^2) \times .785 \times c = (5.5^2 - 4.3^2) \times .785 \times 2.4$	22.15
$\Sigma V =$	80.28

$W = \Sigma V \times \rho = 80.28 \times .291 = \underline{23.30\ LBS}$

F H Ecnwit — PREPARED BY | 5-15-68 — DATE | JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY | REPORT NO.

CHECKED BY | DATE | PROJECT

TITLE WEIGHT CALC. - MOUNTING CELL BRACKET (PRIMARY MIRROR)

SUMMARY

		WEIGHT (LBS)	
2 m A	RING CLAMP	1.81	
3 m A	SPLIT RING	3.0	
4 m A	RING SUPPORT	6.03	
5 m A	CENTERING BLOCKS (3)	.078	
6 m A	HUB SUPPORT	23.30	
	TOTAL		34.218

CLASSIFICATION

JPL 0999-1-S APR 66

F H BENNIT
PREPARED BY

5-20-68
DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO

CHECKED BY

DATE

PROJECT

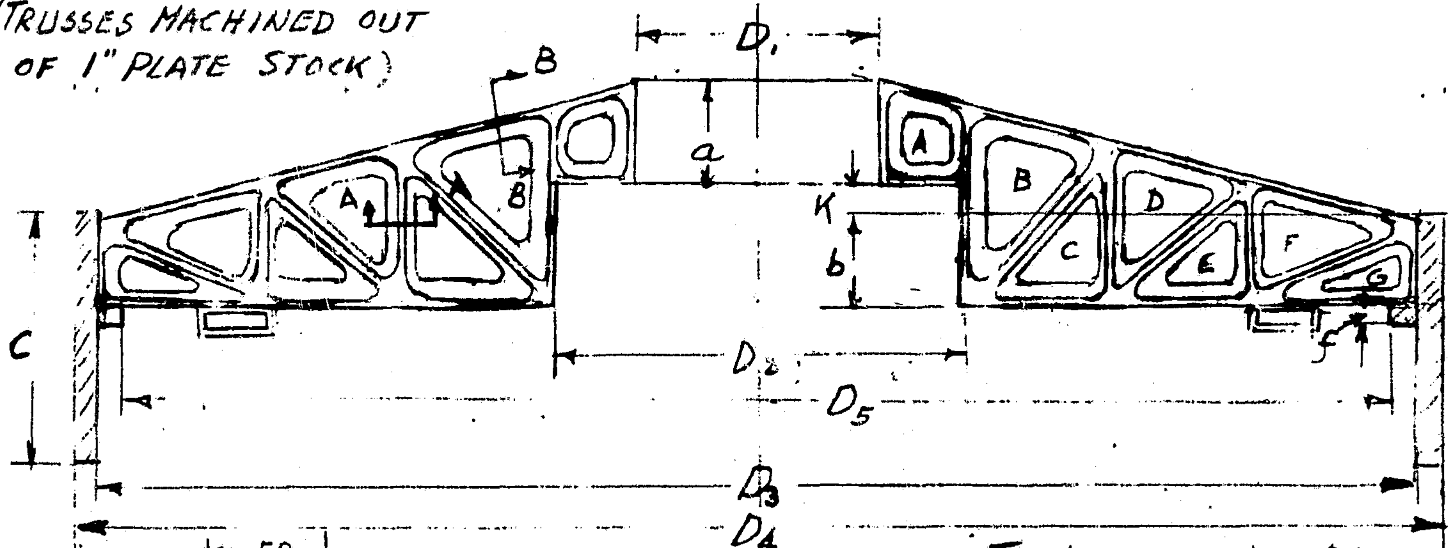
TITLE
WEIGHT CALC. - BASE MOUNTING RING. (PRIMARY MIRROR)

16A

BASE MOUNTING RING AND TRUSSES

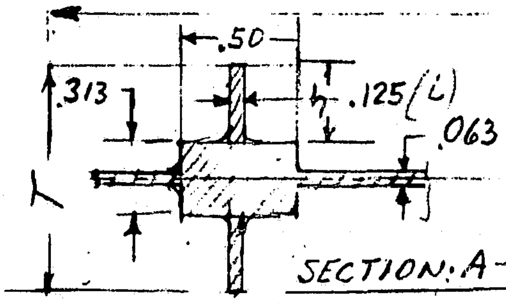
MATL. INVAR "36" $\rho = .291\ \#/IN^3$

(TRUSSES MACHINED OUT OF 1" PLATE STOCK)



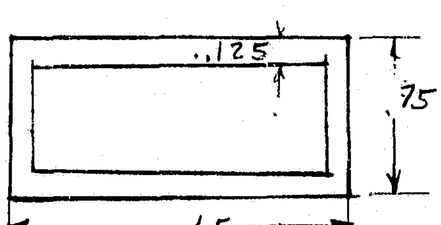
$D_1 = 5.5$
$D_2 = 8.5$
$D_3 = 29.0$
$D_4 = 30.0$
$D_5 = 27.8$
$a = 2.3$
$b = 1.8$
$c = 5.5$
$e = .063$
$f = .50$
$K = .70$

$T = 1.0$ $\quad h = .344$ $\quad h_1 = .125$



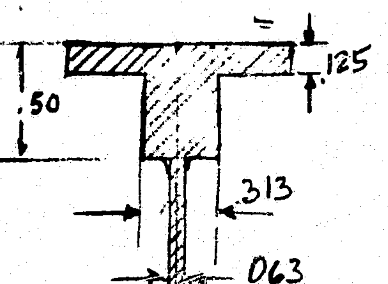
SECTION: A-A

	IN^3	
$V_1 = (D_4^2 - D_3^2) \times .785 \times c = (30.0^2 - 29.0^2) \times .785 \times 5.5$	255.00	
(LEDGE) $V_2 = (D_3^2 - D_5^2) \times .785 \times f = (29.0^2 - 27.8^2) \times .785 \times .5 =$	26.70	
ΣV (RING)	281.70	*
1" BLANKS $V_3 = [3(D_3 - D_2) \times b + 1.5(D_3 - D_1)(a+K) - 3(D_2 - D_1)K]T$		
$= [3(29.0-8.5) \times 1.8 + 1.5(29.0-5.5)3.0 - 3(8.5-5.5).7] \times 1.0 =$	209.80	
$V_4 = 12(A_A + A_B + A_C + A_D + A_E + A_F + A_G)h =$		
$= 12(3.0 + 7.0 + 4.75 + 4.5 + 2.25 + 3.5 + 3.0) \times .344$	-120.00	
$V_5 = 12(A_{A_1} + A_{B_1} + A_{C_1} + A_{D_1} + A_{E_1} + A_{F_1} + A_{G_1})h_1 =$		
$= 12(1.0 + 3.4 + 3.0 + 2.25 + 1.2 + 1.9 + .64) \times .125 =$	-20.20	
(6) RIBS OR TRUSSES	69.60	*
(6 □) $V_6 = A_\square \times 6 \times L = .5 \times 6 \times 12.75$	38.30	*
ΣV	389.60	



$A_\square = 4.0 \times .125 = .5\ IN^2$

$L = 12.75$ [℄ TO ℄ RIBS]



SECT. B-B

$\Sigma W = \Sigma V \times \rho = 389.60 \times .291 = \underline{113.0\ LBS}$

RING + LEDGE ONLY: $281.7 \times .291 = \underline{81.8\ LBS}$

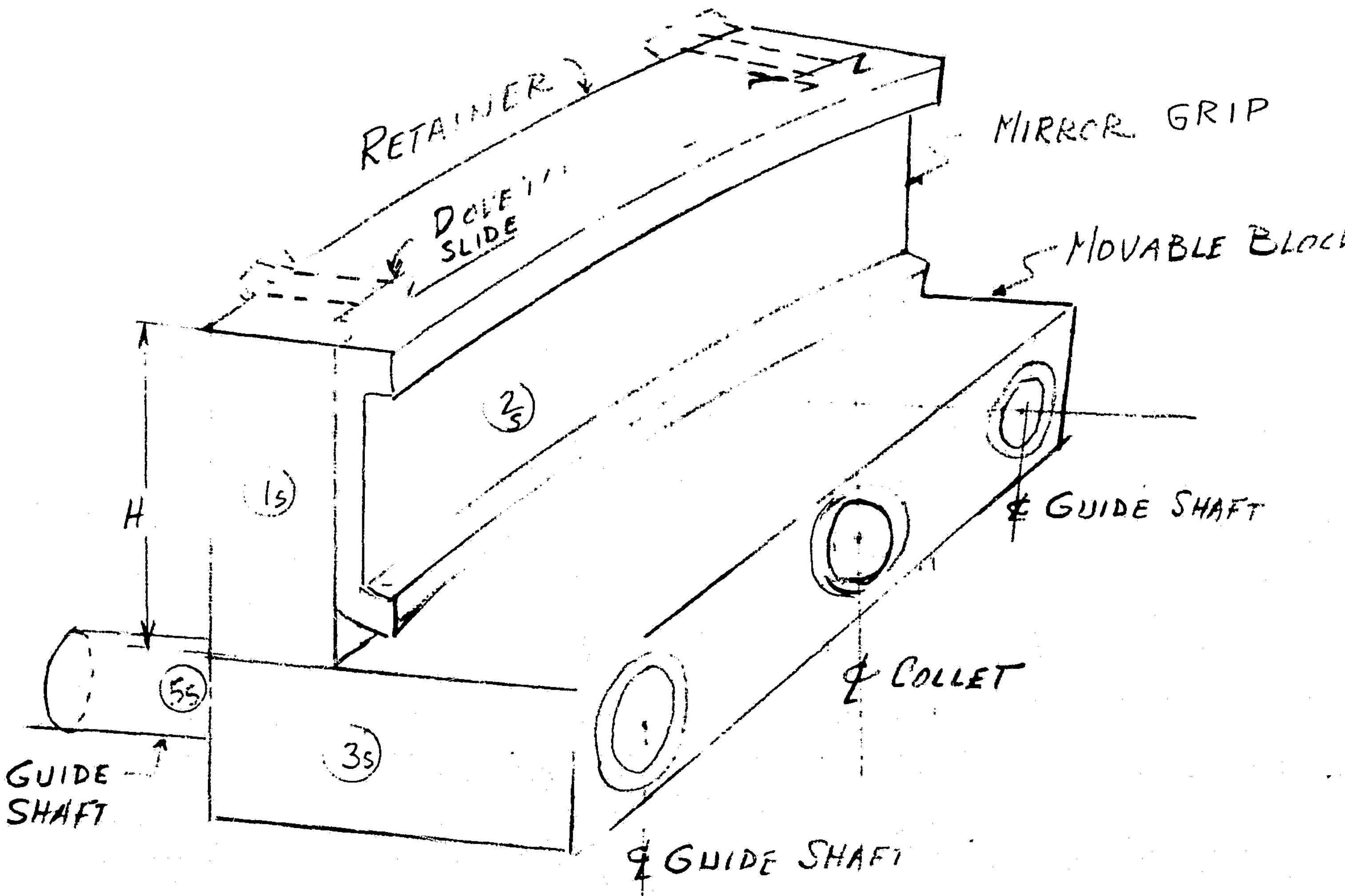
SINGLE TRUSS ONLY: $\frac{69.60}{6} \times .291 = \underline{3.37\ LBS}$

CLASSIFICATION

JPL 2999-1-S APR 66

PREPARED BY	DATE		REPORT NO.
F. H. Bonnit	5-6-68	JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

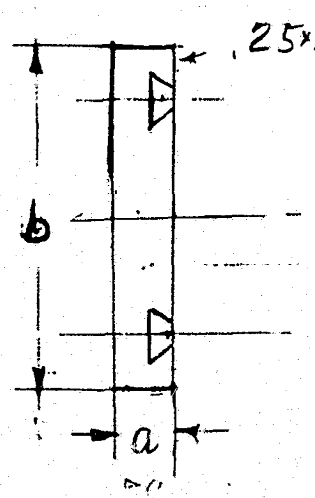
TITLE WEIGHT CALC. - SUPPORT LAUNCH LOCK ASSY. (PRIMARY MIRROR;



1s RETAINER

MATL.: INVAR "36"; $\rho = .291 \#/IN^3$

$b = 4.5 \quad a = 7.5 ; H = 1.6$



		IN^3
	$V_1 = a \times b \times H = 7.5 \times 4.5 \times 1.6 =$	5.4
2 (DOVE TAILS)	$V_2 = 2 \times .25 \times .8 \times 1.6$	- .64
		4.76

$W = \Sigma V \times \rho = 4.76 \times .291 = \underline{\underline{1.39 \text{ LBS}}}$

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BENNIT — PREPARED BY — 5-7-68 — DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

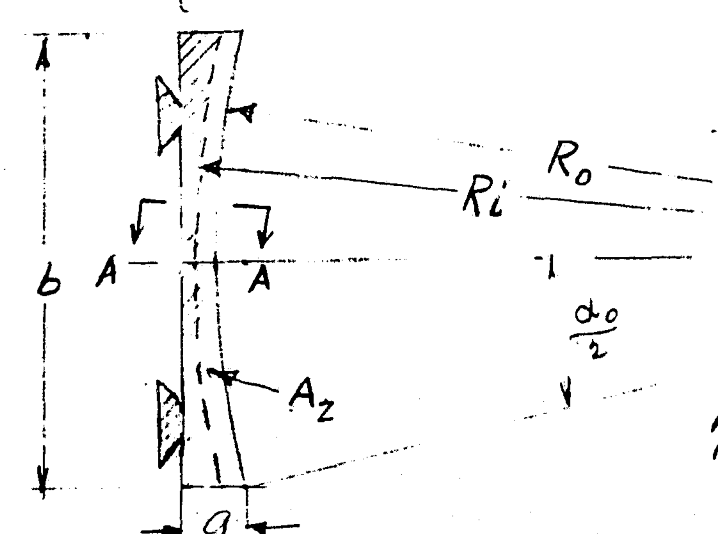
REPORT NO.

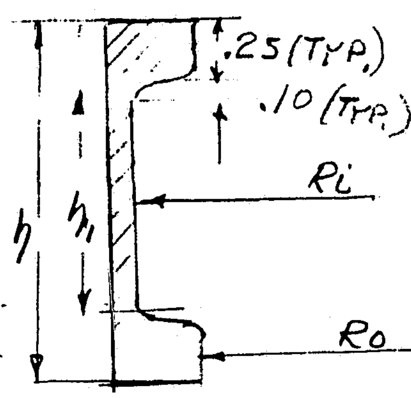
CHECKED BY — DATE — PROJECT

TITLE: WEIGHT CALC. - SUPPORT LAUNCH LOCK (PRIMARY MIRROR)

2s MIRROR GRIP

(3) - .2 × .4 DOVETAILS





MATL.: INVAR 36"
$\rho = .291\ \#/IN^3$

$R_o = 12.75$

$R_i = 13.0$

$a = .75$

$b = 4.5 \quad h = 1.5$

$h_1 = h - 2\times(.25+.05) = 1.5 - (2\times.3) = .90$

	IN^3
$V_1 = a\times b\times h = .75\times 4.5\times 1.5$	~~6.75~~ 5.05

$f_o = \sqrt{R_o^2 - \frac{b^2}{4}} = \sqrt{12.75^2 - \frac{4.5^2}{4}} =$

$f_o = 12.55$

$A_{oo} = R_o^2\pi = (12.75)^2\pi = 510.71\ IN^2$

$tg\frac{\alpha_o}{2} = \frac{b}{2}/f_o = \frac{2.25}{12.55} = .179;\ \frac{\alpha_o}{2} = 10.25°;\ \alpha_o = 20.50'$

$A_{\Delta_o} = f_o\times\frac{b}{2} = 12.55\times 2.25$
$28.20\ IN^2$

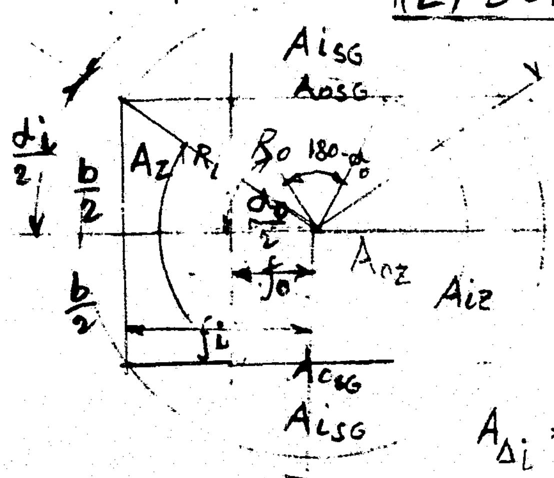
$A_{SECT.} = A_{oo}\times\frac{\alpha_o}{2\pi} = 510.71\times\frac{20.50}{360} = 29.10\ IN^2$

$A_{SEGMT.} = A_{SECT.} - A_{\Delta} = 29.1 - 28.20 = .90\ IN^2$; $\boxed{V_2 = A_{SEGMT}\times h = .90\times 1.5}$ .0757 — 1.35

3.70

$\boxed{(2)\ \text{DOVETAILS}:\ V_3 = 2\times.6\times.25\times h = 2\times.6\times.25\times1.5}$ + .45

4.15



$f_i = \sqrt{R_i^2 - \frac{b^2}{4}} = \sqrt{13.0^2 - \frac{4.5^2}{4}} = 12.8$; $A_{\Delta_o} = f_o\times\frac{b}{2} = 28.2\ IN^2$

$A_{osc} = A_{oo}\times\frac{(180-\alpha_o)}{2\pi} = 510.71\times\frac{159.50}{360} = 226.2\ IN^2$

$A_{osG} = A_{osc} - A_{\Delta_o} = 226.2 - 28.2 = 198.0\ IN^2$

$A_{oz} = A_{oo} - 2A_{osG} = 510.71 - 2(198.0) = 114.71\ IN^2$

$A_{\Delta_i} = f_i\times\frac{b}{2} = 12.8\times 2.25 = 28.8\ IN^2$; $\boxed{V_4 = A_z\times h_1 = 1.45\times.90}$ — 1.30

$tg\frac{\alpha_i}{2} = \frac{b}{2}/f_i = \frac{2.25}{12.8} = .175;\ \alpha_i = 10°;\ \alpha_i\ 20.0°$; $A_{io} = R_i^2\pi = 13.0^2\pi = 532.0\ IN^2$

$A_{isc} = A_{io}\times\frac{(180-\alpha_i)}{2\pi} = 532.0\times\frac{160.0}{360} = 236.0\ IN^2$; $A_{isG} = A_{isc} - A_{\Delta_i} = 236.0 - 28.8 = 207.2\ IN^2$

$A_{iz} = A_{io} - 2A_{isG} = 532.0 - 2(207.2) = 117.6\ IN^2$; $A_z = \frac{A_{iz} - A_{oz}}{2} = \frac{117.6 - 114.71}{2} = 1.45\ IN^2$

ΣV 2.85

*) SEE PG. 7

$W = \Sigma V\times\rho = 2.85\times.291 = \underline{\underline{.83\ LBS}}$

F H BONWIT — PREPARED BY | 5-8-68 — DATE | JET PROPULSION LABORATORY | REPORT NO.
CHECKED BY | DATE | CALIFORNIA INSTITUTE OF TECHNOLOGY | PROJECT

TITLE WEIGHT CALC. – SUPPORT LAUNCH LOCK (PRIMARY MIRROR)

3S MOVABLE BLOCK

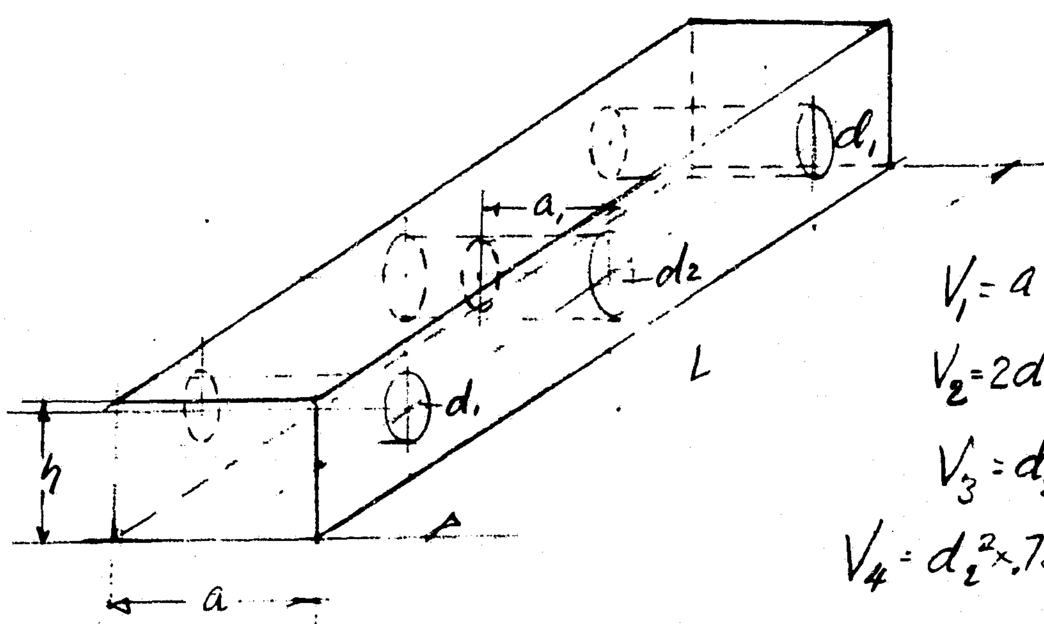
MATL.: INVAR "36"; $\rho = .291$ #/IN^3

$a = 1.75 \quad d_1 = .50$

$L = 4.5 \quad d_2 = .65$

$h = 1.1 \quad a_1 = 1.1$

$d_3 = .75$



	IN^3
$V_1 = a \times L \times h = 1.75 \times 4.5 \times 1.1 =$	8.67
$V_2 = 2d_1^2 \times .785 \times a = 2 \times .5^2 \times .785 \times 1.75$	– .68
$V_3 = d_2^2 \times .785 \times a_1 = .65^2 \times .785 \times 1.1$	– .36
$V_4 = d_2^2 \times .785(a - a_1) = .75^2 \times .785 \times .65$	– .29
ΣV	7.34

$W = \Sigma V \times \rho = 7.34 \times .291 = \underline{2.14\ LBS}$

4S STATIONARY BLOCK

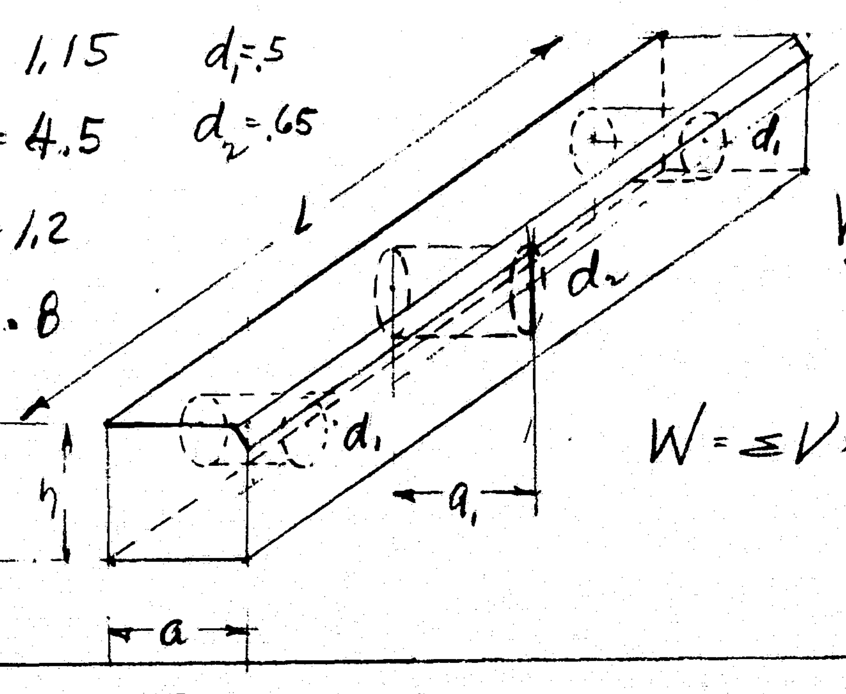
MATL. INVAR "36"; $\rho = .291$ #/IN^3

$a = 1.15 \quad d_1 = .5$

$L = 4.5 \quad d_2 = .65$

$h = 1.2$

$a_1 = .8$

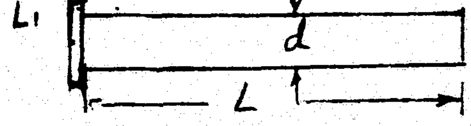


	IN^3
$V_1 = a \times L \times h = 1.15 \times 4.5 \times 1.2 =$	6.2
$V_2 = 2d_1^2 \times .785 \times a = 2 \times .5^2 \times .785 \times 1.15$	– .46
$V_3 = d_1^2 \times .785 \times a_1 = .65^2 \times .785 \times .8$	– .27
	5.47

$W = \Sigma V \times \rho = 5.47 \times .291 = \underline{1.59\ LBS}$

5S GUIDE SHAFT (S)

$d = .45;\ L = 3.3$ MATL.: INVAR "36"; $\rho = .291$ #/IN^3



$d_1 = .75;\ L_1 = .1$

IN^3

$V_1 = d^2 \times .785 \times L + d_1^2 \times .785 \times L_1 = .45^2 \times .785 \times 3.3 + .75^2 \times .785 \times .1 = .575$

$W\ OF\ (2) = 2V_1 \times \rho = 2 \times .575 \times .291 = \underline{.33\ LBS}$

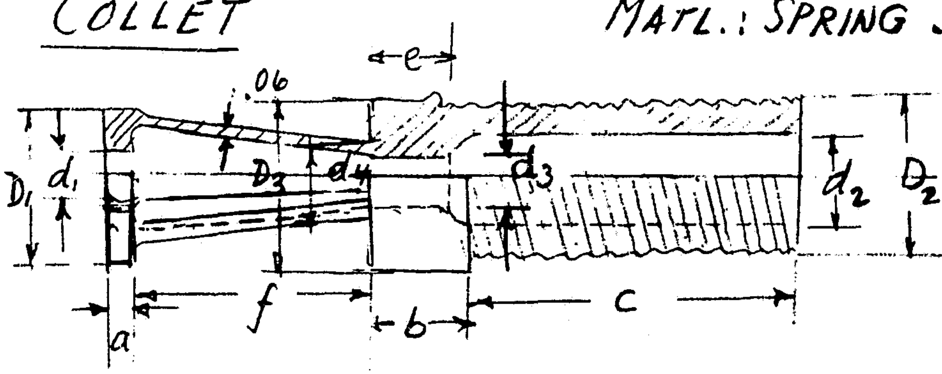
PAGE 11A OF ____

F.H. Bonwit — PREPARED BY | 5-8-68 — DATE | JET PROPULSION LABORATORY | REPORT NO.

CHECKED BY | DATE | CALIFORNIA INSTITUTE OF TECHNOLOGY | PROJECT

TITLE WEIGHT CALC. – SUPPORT LAUNCH LOCK (PRIMARY MIRROR)

6S COLLET — MATL.: SPRING STEEL; $\rho = .283\ \#/IN^3$



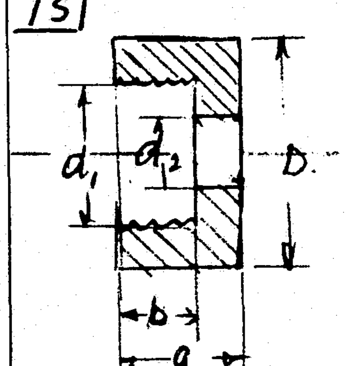
$a = .1$, $b = .4$, $c = 1.5$, $f = 1.0$

$D_1 = .6$, $D_2 = .7$, $D_3 = .8$, $d_1 = .25$, $d_2 = .40$, $d_3 = .25$, $d_4 = .35$

	IN^3
$V_1 = .785(D_2^2 - d_2^2) \times c = .785(.7^2 - .4^2) \times 1.5 =$	.39
$V_2 = .785(D_3^2 - d_3^2) \times b = .785(.8^2 - .25^2) \times .4 =$	.18
$V_3 = .785(D_1^2 - d_1^2) \times a = .785(.6^2 - .25^2) \times .1 =$	.02
$V_4 = \pi \frac{(D_1 + d_4)}{2 \times 6} \times .06 \times f = \pi\left(\frac{.6 + .35}{12}\right) \times .06 \times 1.0$	.02
ΣV	.61

$W = \Sigma V \times \rho = .61 \times .283 = \underline{.172\ LBS}$

7S END CAP — MATL.: INVAR "36"; $\rho = .291\ \#/IN^3$



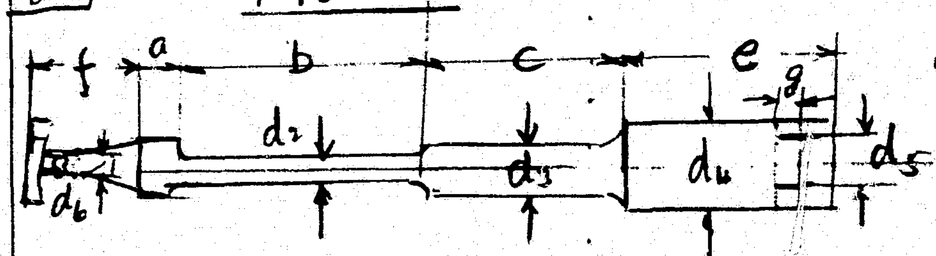
$D = 1.0$, $d_1 = .6$, $d_2 = .3$

$a = .55$, $b = .35$

	IN^3
$V_1 = .785 D^2 \times a = .785 \times 1.0^2 \times .55$	.432
$V_2 = .785 d_1^2 \times b = .785 \times .6^2 \times .35$	– .100
$V_3 = .785 d_2^2 \times (a - b) = .785 \times .3^2 \times .20$	– .014
ΣV	.318

$W = \Sigma V \times \rho = .318 \times .291 = \underline{\sim .10\ LBS}$

8S PISTON — MATL.: INVAR "36" $\rho = .291$



$a = .2$; $b = 1.1$; $c = .9$; $e = .9$; $f = 1.8$; $g = .1$

$d_1 = .2$; $d_2 = .1$; $d_3 = .25$; $d_4 = .4$; $d_5 = .3$; $d_6 = .2$

$V_1 = .785[d_1^2 \times a + d_2^2 b + d_3^2 c + d_4^2 e - (d_4^2 - d_5^2) g + d_6^2 f]$

$V_1 = .785[.2^2 \times .2 + .1^2 \times 1.1 + .25^2 \times .9 + .4^2 \times .9 - (.4^2 - .3^2).1 + .2^2 \times 1.8]$

.008 .011 .057 .144

$V_1 = .280$

$W = V \times \rho = .280 \times .291 = \underline{.08\ LBS}$

CLASSIFICATION

JPL 0999-1-5 APR 66

PAGE 12A OF ______ S

F H Bonwit	5-9-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC - SUPPORT LAUNCH LOCK - SUMMARY (PRIMARY MIRROR)

SUPPORT LAUNCH LOCK (EACH) - ASSY.

		WEIGHT (LBS)	
1S	RETAINER	1.39	A
2S	MIRROR GRIP	.83	A
3S	MOVABLE BLOCK	2.14	
4S	STATIONARY BLOCK	1.59	
5S	GUIDE SHAFT (2)	.33	
6S	COLLET	.17	
7S	END CAP	.10	
8S	PISTON	.05	
			6.60

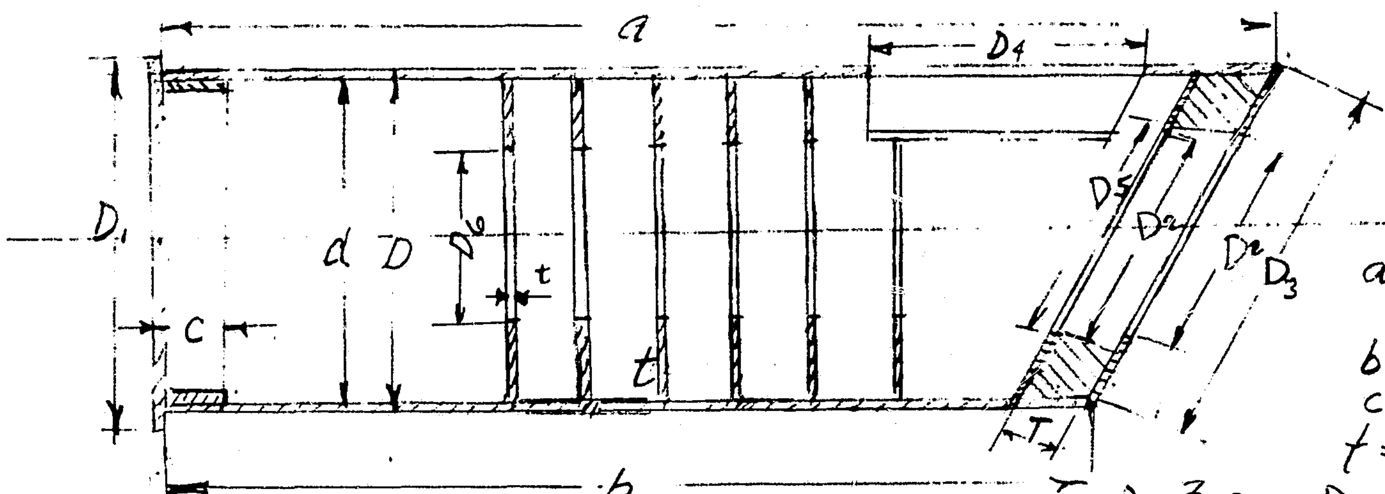
FOR (12) LOCKS $12 \times 6.60 = 79.20$ LBS

CLASSIFICATION JPL 0999-1-S APR 66

F.H. BONWIT
PREPARED BY | DATE | JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY | REPORT NO
CHECKED BY | DATE | PROJECT

TITLE WEIGHT CALC. – ASSEMBLY (SECONDARY MIRROR)

1a MIRROR HOUSING MATL.: 6061 AL.; $\rho = .098 \#/IN^3$



$a = 14.6;\ D = 4.5$

$b = 12.0;\ D_1 = 5.0$

$c = .4$

$t = .100$ TYP.

$D_6 = 3.2;\ D_2 = 3.00;\ D_3 = 5.0;\ D_4 = 3.0$

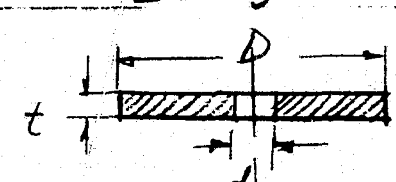
$D_5 = 3.4$ (APPR)

$D - 2t : d = 4.5 - .2 = 4.30;\ \frac{a+b}{2} = m = \frac{14.6+12.0}{2} = 13.3$ $T = .8$

	IN^3
$V_1 = (D^2 - d^2) \times .785 \times m = (4.5^2 - 4.3^2) \times .785 \times 13.3 =$	18.35
$V_2 = D_1^2 .785 \times t = (5.0^2) .785 \times .100 =$	+ 1.96
$V_3 = 2 \times (D_3^2 - D_2^2) .785 \times t = 2(5.0^2 - 3.0^2) \times .785 \times .100$	+ 2.51
	22.82
$V_4 = D_4^2 \times .785 \times t = 3.0^2 \times .785 \times .100$	− .71
	22.11
$V_5 = d \times \pi \times t \times c = 4.30 \times \pi \times .100 \times .4 =$	+ .54
$V_6 = (D_3^2 - D_5^2) \times .785 \times T = (5.0^2 - 3.4^2) \times .785 \times .8$	+ 8.46
[ADDED (6) STIFFENERS] $V_7 = (d^2 - D_6^2) \times .785 \times t \times 6 = (4.3^2 - 3.2^2) \times .785 \times .1 \times 6$	3.89
$\Sigma V =$	35.00

$W = \Sigma V \times \rho = 35.0 \times .098 = \underline{3.43 \text{ LBS}}$

2a FIRST DIAGONAL MATL.: U.L.E. FUSED SILICA #7971 (CORNING GLASS) $\rho = .08 \#/IN^3$



$t = .3;\ D = 3.5$) APPR. $d = .5$

$V = (D^2 - d^2) .785 \times t = (3.5^2 - .5^2) .785 \times .3 = 2.47\ IN^3$

$W = V \times \rho = 2.47 \times .08 = \underline{.20 \text{ LBS}}$

CLASSIFICATION JPL 0999-1-S APR 66

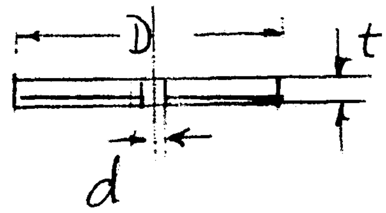
F.H. BONWIT — PREPARED BY — 5-9-68 DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

CHECKED BY — DATE — REPORT NO — PROJECT

TITLE: WEIGHT CALC. - SECONDARY MIRROR ASSY.

3a HEAT STOP MIRROR



MATL.: 6061 AL. COATED WITH FUSED SILICA

$\rho = .75 \times .098 + .25 \times .08 = .0935 \#/IN^3$

$t = .20 ;\ D = 3.5 ;\ d = .25$

$V = (D^2 - d^2).785 \times t = (3.5^2 - .25^2).785 \times .25 = 2.39\ IN^3$ (12.18)

$W = V \times \rho = 2.39 \times .0935$ $\underline{\underline{.223\ LBS}}$

4a SEALING DISKS

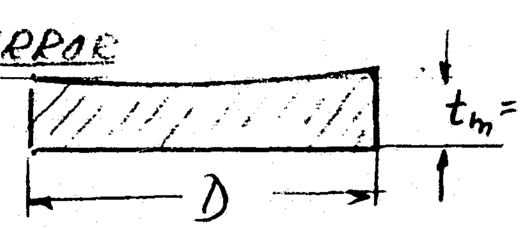
MATL. 6016 AL $\rho = .098 \#/IN^3$

$D = 3.5 ;\ d = .25 ;\ t = .05$

$V = (D^2 - d^2).785 \times t = (3.5^2 - .25)^2 .785 \times .05 \times 2 = .95\ IN^3$

$W = V\rho = .95 \times .098 = \underline{\underline{.0934\ LBS}}$

5a SECONDARY MIRROR



MATL.: U.E.L. FUSED SILICA #7971 (C. GL. WKS)

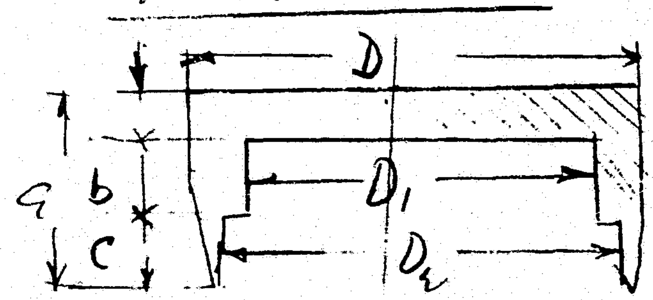
$\rho = .08 \#/IN^3$

$D = 3.0 \quad t_m = .5$

$V = D^2 .785 \times t = 3.0^2 \times .785 \times .5 = 3.53\ IN^3$

$W = V \times \rho = 3.53 \times .08 = .282\ LBS$

6a MIRROR GRIP



MATL.: 6061 AL. $\rho = .098 \#/IN^3$

$D = 4.0,\ D_1 = 3.0 ;\ D_2 = 3.5$

$a = 1.6 \quad b = .6 \quad c = .5$ APPR

	IN^3
$V_1 = D^2 .785 \times a = 4.0^2 .785 \times 1.6 =$	20.10
$V_2 = D_1^2 \times .785 \times b = 3.0^2 \times .785 \times .6 =$	$-$ 4.23
$V_3 = D_2^2 .785 \times c = 3.5^2 .785 \times .5$	$-$ 4.82
FOR TUBING	.25
$\Sigma V =$	10.80

$W = V \times \rho = 10.80 \times .098 = \underline{\underline{1.06\ LBS}}$

CLASSIFICATION

JPL 0999-1-S APR 66

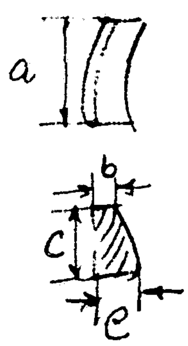
FH BENNIT
PREPARED BY | DATE | JET PROPULSION LABORATORY | REPORT NO.

CHECKED BY | DATE | CALIFORNIA INSTITUTE OF TECHNOLOGY | PROJECT

TITLE WEIGHT CALC. - SECONDARY MIRROR ASSY. - SUMMARY

7a

SEAT WEDGES (3) MTL.: 6061 AL.; $\rho = .098 \#/IN^3$



$a = .75$; $b = .25$; $c = .75$; $e = .4$

$V = c\left(\frac{b+e}{2}\right) \times a = .75\left(\frac{.25+.4}{2}\right) .75 = .1828\ IN^3$

$W = (3)\ .1828 \times .098 = \underline{.0537\ LBS}$

8a Misc.: (3) LUGS, BOLTS, NUTS, TUBING ETC

W = .25 LBS

SECONDARY MIRROR ASSY. - SUMMARY

		WEIGHT (LBS)
1a	MIRROR HOUSING	3.03
2a	FIRST DIAGONAL	.20 ✓
3a	HEAT STOP MIRROR	.223 ✓
4a	SEALING DISKS	.093
5a	SECONDARY MIRROR	.282 ✓
6a	MIRROR GRIP	1.06
7a	SEAT WEDGES (3)	.054
8a	Misc. LUGS, BOLTS, NUTS ETC	.25
9a	SPIDER RING	56.30
10a	SPIDERS (4)	6.09
11a	5 FT. OF .25 ϕ TUBING	.353
12a	COMPONENTS (MOTORS ETC.)	12.49
		80.41

CLASSIFICATION

JPL 0999-1-S APR 66

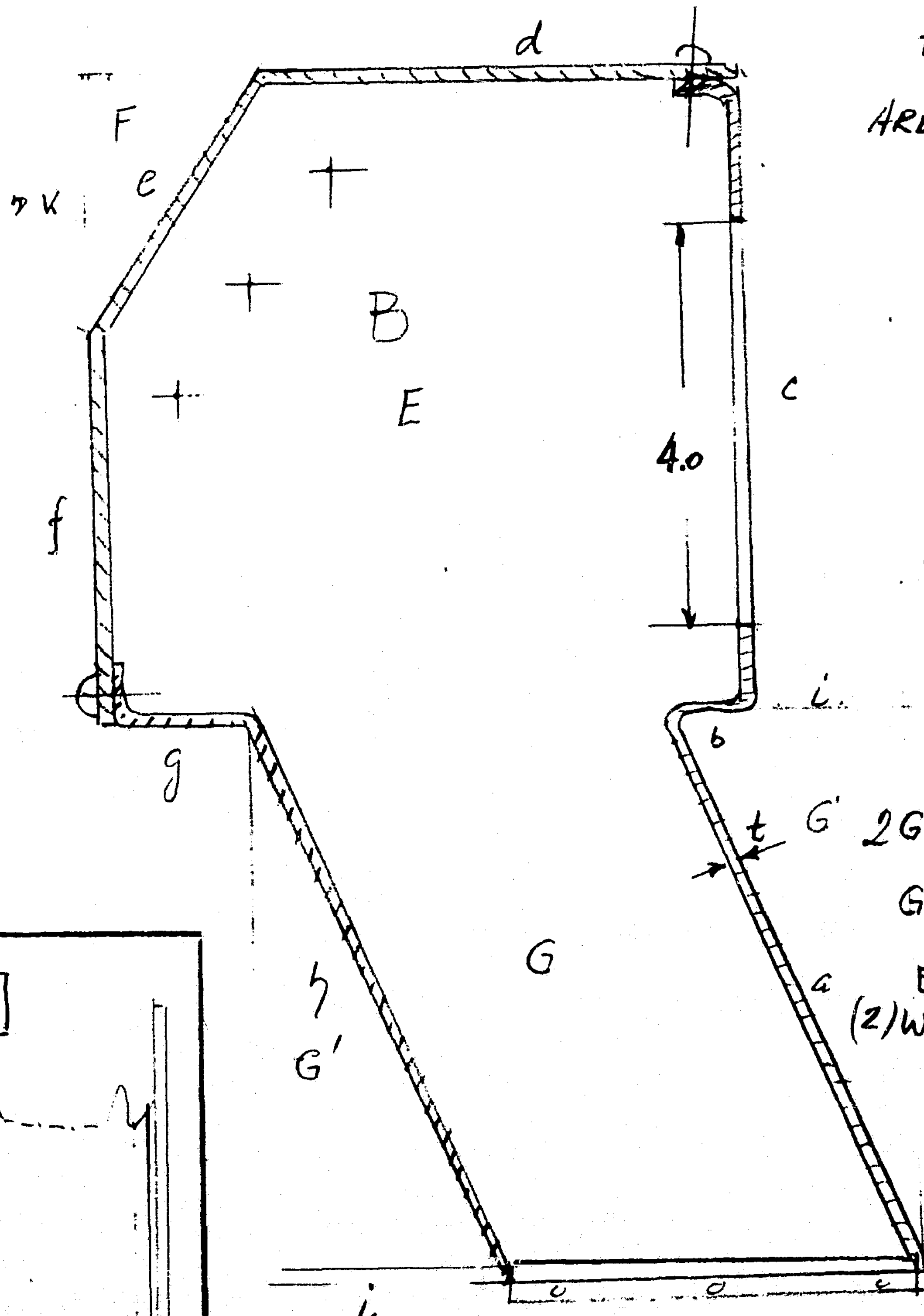
F. H. BONWIT
PREPARED BY — DATE
CHECKED BY — DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO.
PROJECT

TITLE: WEIGHT CALC. – 2^{ND} DIAGONAL MIRROR – ASSY

1d HOUSING



MATL.: 6061 T6 AL; $\rho = .098\,\#/cu$

$t = .090\,IN, \quad 1.27\,\#/FT^2 = \rho'$

AREAS:

a = 6.25 IN b = .8
c = 6.50 d = 4.85
e = 2.99 f = 4.00
g = 1.4 h = 6.25

17.14 15.80
+ 15.80

$A_1 = 32.94\,IN \times 5.25 = 173.00\,IN^2$

$A_2 = A_1 - (4^2 \times .785) = 173.0 - 12.55 = 160.45\,IN^2$
12.55

K = 2.50

$E = B - F = (6.50^2) - \left(\frac{2.50 \times 1.65}{2}\right) =$
$= 42.25 - 2.06 = 40.19\,IN^2$

$2G' = \frac{5.75 \times 2.50 \times 2}{2} = 14.36$

$G = (5.75 \times 6.50) - 2G' = 37.4 - 14.36 = 23.04\,IN^2$

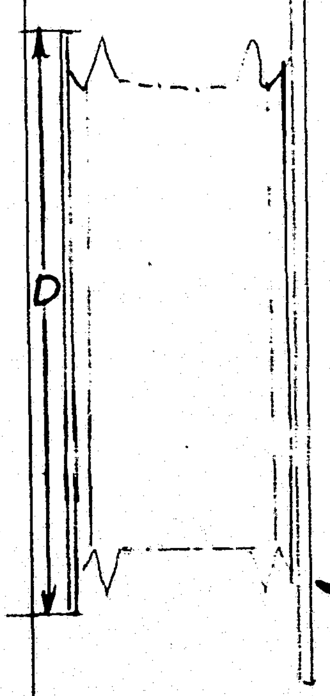
$E + G = 40.19 + 23.04 = 63.23$

(2) WALLS:
$2(E+G) = 126.46\,IN^2$

$A_2 + 2(E+G) = 160.45 + 126.46 = \Sigma A =$
$\Sigma A = 286.91\,IN^2$ OR
$\frac{286.91}{144} = 1.99\,FT^2$

$W = \Sigma A \times \rho' = 1.99 \times 1.27 = \underline{\underline{2.53\,LBS}}$

2d



BELLOWS

PART # 60090 (METAL BELLOWS CORP.) $W_B = .75\,LB$ (BY TELEPHONE)

$\boxed{W = W_B + W_F = .75 + .242 = .992\,LBS}$

FLANGE: O.D. = 6.50
I.D = 4.00
T = .125

MATL. 6061 AL
$\rho = .098\,\#/IN^3$

$(OD^2 - ID^2) .785 \times T = (6.5^2 - 4.0^2) \times .784 \times .125 = \Sigma V_F = 2.475\,IN^3$

$W_F = V_F \times \rho = 2.475 \times .098 = .242\,LBS$

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BONNIT — PREPARED BY — 5-13-68 DATE — JET PROPULSION LABORATORY — REPORT NO.

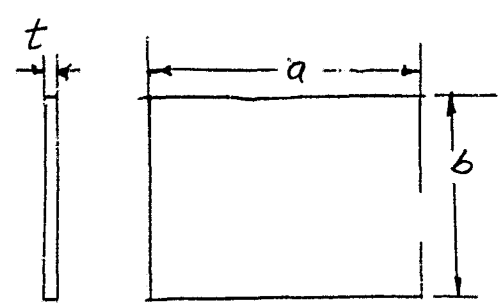
CHECKED BY — DATE — CALIFORNIA INSTITUTE OF TECHNOLOGY — PROJECT

TITLE: WEIGHT CALC. – 2ND DIAGONAL – MIRROR ASSY. – REF. DWG. 10026213

3d ADJUSTMENT PLATE MATL. 6061-T6 ALUM. $\rho = .098\ \#/IN^3$

REF. DWG. 10026219

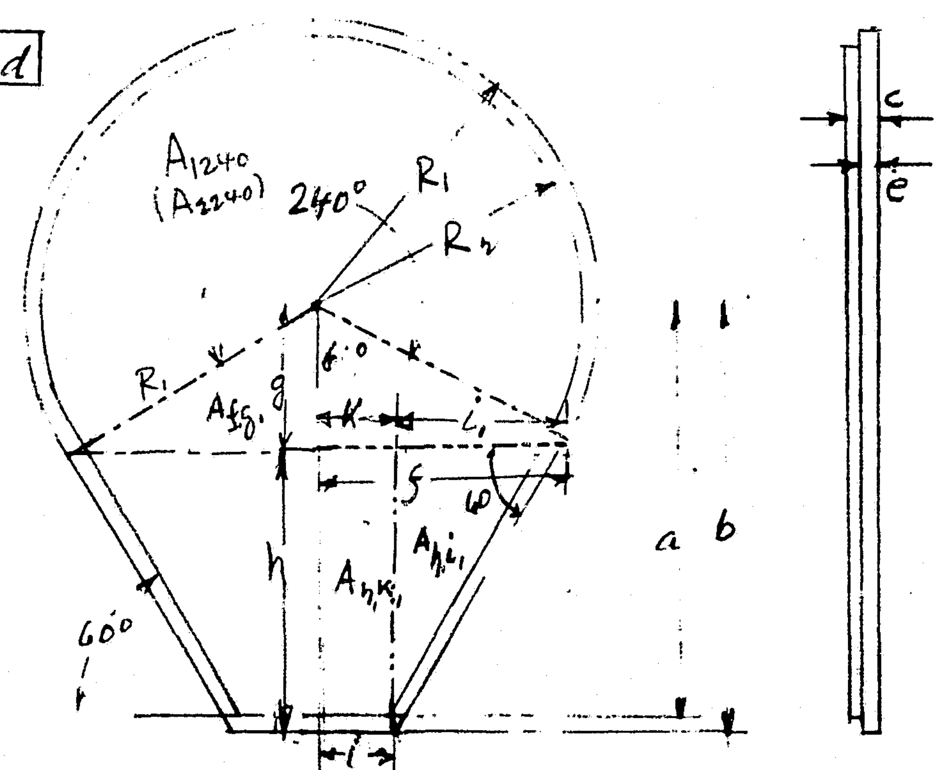
$a = 5.00$
$b = 3.75$
$t = 2.50$



$V = a \times b \times t = 5.0 \times 3.75 \times .25 = 4.675\ IN^3$

$W = V \times \rho = 4.675 \times .098 = \underline{.457\ LBS}$

4d



2ND DIAGONAL MIRROR

$R_1 = 5.0\ cm = 1.969\ IN$ MATL.: U.L.E.

$R_2 = 4.7\ cm = 1.85\ IN$ FUSED SILICA

$a = 7.25\ cm = 2.85\ IN$ #7971 (C.GL.WKS)

$\rho = .08\ \#/IN^3$

$b = 7.5\ cm = 2.95\ IN$

$c = .700\ cm = .276\ IN$

$e = .5\ cm = .197\ IN$ $A_{2240} = \frac{240}{360} R_2^2 \pi = 7.16\ IN^2$

$A_{1240} = \frac{240}{360} R_1^2 \pi = 8.11\ IN^2$

$V_1 = [A_{1240} + 2A_{fg_1} + 2A_{hi_1} + 2A_{Kh_1}]\,e$	IN^3
$V_1 = [8.11 + 1.677 + 2.22 + 1.123] \times .197$	2.586
$V_2 = [A_{2240} + 2A_{f_2g_2} + 2A_{h_2i_2} + 2A_{Kh_2}] \times (c-e)$	
$V_2 = [7.16 + 1.48 + 2.136 + 1.894] \times .097 =$	1.229
$\Sigma V =$	3.815

$\sin 60° = \frac{f_1}{R_1};\ f_1 = R_1 \sin 60° = 1.969 \times .866 = 1.705$

$\cos 60° = \frac{g}{R_1};\ g_1 = R_1 \cos 60° = 1.969 \times .5 = .984$

$A_{fg} = \frac{f_1 g_1}{2} = \frac{1.705 \times .984}{2} = \frac{1.677}{2}\ IN^2;$

$h_1 = b - g = 2.95 - .984 = 1.966;\quad \cot 60° = \frac{i_1}{h_1};$

$i_1 = h_1 \times \cot 60° = 1.966 \times .577 = 1.134$

$K_1 = f_1 - i_1 = 1.705 - 1.134 = .571$ $A_{hi_1} = \frac{h_1 \times i_1}{2} = \frac{1.966 \times 1.134}{2} = \frac{2.22}{2}\ IN^2$

$A_{hK_1} = h_1 \times K_1 = 1.966 \times .571 = 1.123\ IN^2$

$f_2 = R_2 \sin 60° = 1.85 \times .866 = 1.602$

$g_2 = R_2 \cos 60° = 1.85 \times .5 = .925$

$A_{fg} = \frac{f_2 g_2}{2} = \frac{1.602 \times .925}{2} = \frac{1.48}{2}\ IN^2;$ $A_{h_2i_2} = \frac{h_2 \times i_2}{2} = \frac{1.925 \times 1.110}{2} = \frac{2.136}{2}\ IN^2$

$h_2 = a - g_2 = 2.85 - .925 = 1.925$

$i_2 = h_2 \cot 60 = 1.925 \times .577 = 1.110$

$K_2 = f_2 - i_2 = 1.602 - 1.110 = .492$

$A_{hK_2} = h_2 \times K_2 = 1.925 \times .492 = .947\ IN^2$

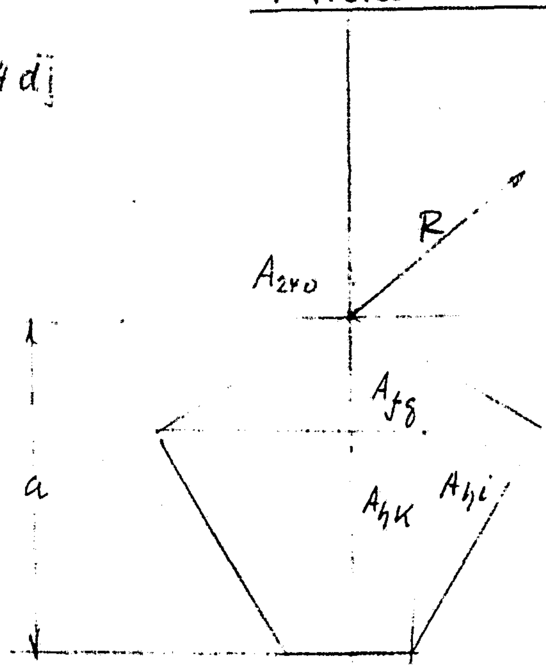
$W = \Sigma V \times \rho = 3.815 \times .08 = \underline{.305\ LBS}$

F. H. BONWIT	5-13-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE	CALIFORNIA INSTITUTE	REPORT NO
		OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC - 2ND DIAGONAL MIRROR ASSY. - REF. DWG. 1002621

5d MIRROR · BOTT. PAD — MATL.: TEFLON, $\rho = .0795\ \#/IN^3$

[SEE 4d]



$t = .002 \quad a = 2.96$

$R = 1.980$

$A_{240} = \frac{240}{360} \times R^2\pi = 8.35\ IN^2$

$f = 1.98 \times .866 = 1.72; \quad A_{fg} = \frac{1.72 \times .99}{2} = \frac{1.70}{2}\ IN^2$

$g = 1.98 \times .5 = .99$

$h = a - g = 2.96 - .99 = 1.97; \quad A_{hi} = \frac{1.97 \times 1.135}{2} = \frac{2.24}{2}\ IN^2$

$i = 1.97 \times .577 = 1.135$

$K = 1.72 - 1.135 = .585 \quad A_{hK} = 1.97 \times .585 = 1.15\ IN^2$

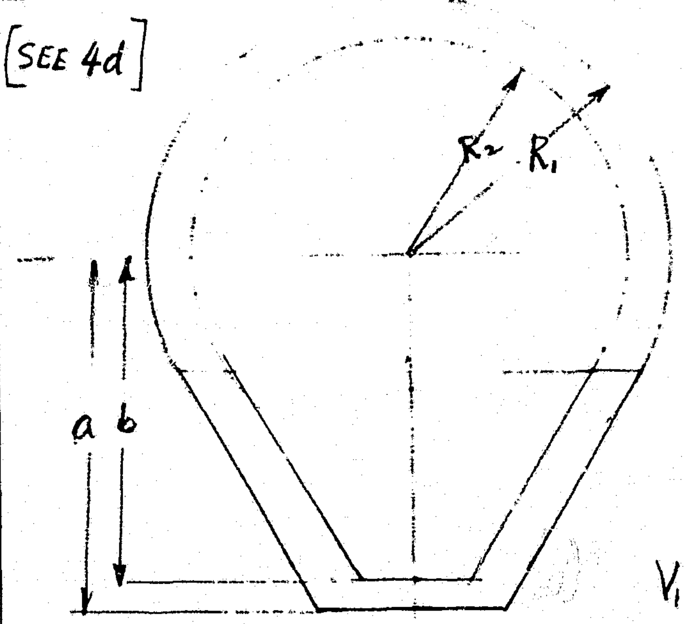
	IN^3
$V = [A_{240} + 2A_{fg} + 2A_{hi} + 2A_{Kh}]\,t =$	
$= [8.35 + 1.7 + 2.24 + 2.3] \times .002 =$	.02918

$W = .02918 \times .0795 = \underline{.0023\ LBS}$

6d MIRROR - TOP PAD — NEGLIGIBLE.

7d MIRROR - RING HOLDER — MATL. 6061-T6 ALUM. $\rho = .098\ \#/IN^3$

[SEE 4d]



$t = .125 \quad R_1 = 2.250 \quad R_2 = 1.900$

$a = 3.100; \quad b = 2.875 \quad A_{1240} = \frac{240}{360} 2.25^2 \pi = 10.6\ IN^2$

$f_1 = 2.25 \times .866 = 1.945; \quad A_{f_1g_1} = \frac{1.945 \times 1.125}{2} = \frac{2.19}{2}\ IN^2$

$g_1 = 2.25 \times .5 = 1.125;$

$h_1 = a_1 - g_1 = 3.1 - 1.125 = 1.975 \quad A_{h_1i_1} = \frac{1.975 \times 1.14}{2} = \frac{2.25}{2}\ IN^2$

$i_1 = 1.975 \times .577 = 1.14$

$K_1 = 1.945 - 1.14 = .805 \quad A_{h_1K_1} = 1.975 \times .805 = 1.585\ IN^2$

	IN^3
$V_1 = [A_{240} + 2A_{f_1g_1} + 2A_{h_1i_1} + 2A_{K_1h_1}]\,t =$	
$= [10.6 + 2.19 + 2.25 + 3.170]\,.125 =$	2.23

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT	5-13-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	REPORT NO.
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC. - 2ND DIAGONAL MIRROR ASSY. - REF. DWG. 10026213

7d MIRROR RING HOLDER (CONT'D.)

(SEE 4d)

$t = .125 \quad R_2 = 1.900 \quad b = 2.875$

$A_{2240} = \frac{240}{360} \times 1.9^2 \times \pi = 7.55 \, IN^2$

$f_2 = 1.9 \times .866 = 1.645 \, ; \quad A_{f_2 g_2} = \frac{1.645 \times .950}{2} = \frac{1.560}{2} \, IN^2$

$g_2 = 1.9 \times .5 = .950 \, ;$

$h_2 = b - g_2 = 2.875 - .950 = 1.925$

$i_2 = 1.925 \times .577 = 1.11 \quad A_{h_2 i_2} = \frac{1.925 \times 1.11}{2} = \frac{2.135}{2} \, IN^2$

$K_2 = 1.645 - 1.11 = .535 \quad A_{h_2 K_2} \cdot 1.925 \times .535 = 1.13 \, IN^2$

	IN^3
$V_1 =$	2.23
$V_2 = \left[A_{2240} + 2A_{f_2 g_2} + A_{h_2 i_2} + 2A_{K_2 h_2}\right] t$ $= [7.55 + 1.560 + 2.135 + 2.26] .125$	-1.685
$\Sigma V =$	.545

$W = \Sigma V \times \rho = .545 \times .098 = \underline{\underline{.0534 \; LBS}}$

8d (2) MIRROR ADJ. SCREWS — NEGLIGIBLE

2ND DIAGONAL MIRROR ASSY. - SUMMARY

		WEIGHT (LBS)
1d	HOUSING	2.53
2d	BELLOWS	.992
3d	ADJUSTMENT PLATE	.457
4d	2ND DIAGONAL MIRROR	.305
5d	MIRROR BOTT. PAD	.002
6d+8d	" - TOP " & ADJ. SCREWS	—
7d	MIRROR RING HOLDER	.053
9d	MIRROR HOLDER	.965
	TOTAL	5.304

F H BONWIT — PREPARED BY | 5-13-68 — DATE | JET PROPULSION LABORATORY | REPORT NO.

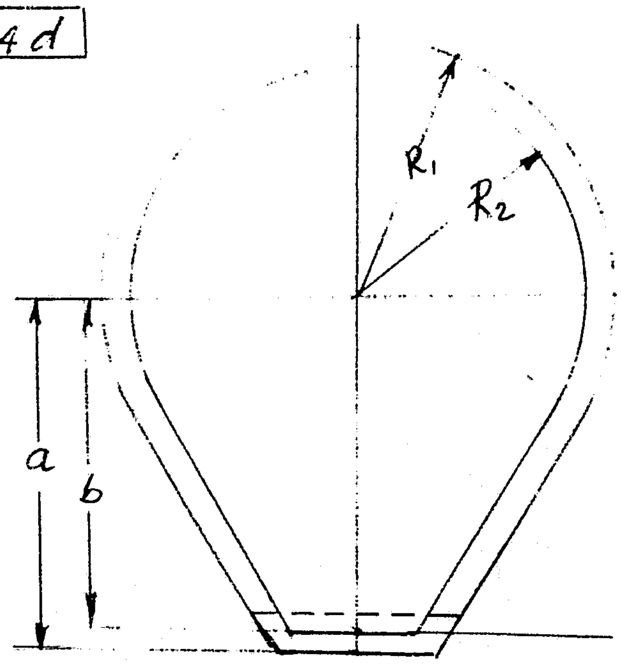
CHECKED BY | DATE | CALIFORNIA INSTITUTE OF TECHNOLOGY | PROJECT

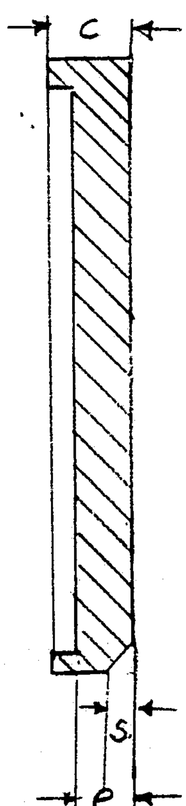
TITLE: WEIGHT CALC. – 2ND DIAGONAL MIRROR ASSY – REF. DWG. 10026213

9d

SEE 4d

MIRROR HOLDER





MATL.: 6061-T6 ALUM. $\rho = .098^{\#}/IN^3$

$R_1 = 2.250$

$R_2 = 1.980$

$a = 3.100 \quad b = 2.962$

$c = .698 \quad e = .500; \; s = .200$

$A_{1240} = \frac{240}{360} R_1^2 \pi = 10.6 \, IN^2$

$A_{2240} = \frac{240}{360} R_2^2 \pi = 8.203 \, IN^2$

$f_1 = 2.250 \times .866 = 1.948$

$g_1 = 2.250 \times .5 = 1.125$

$h_1 = 3.100 - 1.125 = 1.975$

$i_1 = 1.975 \times .577 = 1.140$

$K_1 = 1.948 - 1.140 = .808$

$A_{f_1 g_1} = \frac{1.948 \times 1.125}{2} = \frac{2.192}{2} \, IN^2$

$A_{h_1 i_1} = \frac{1.975 \times 1.140}{2} = \frac{2.252}{2} \, IN^2$

$A_{h_1 K_1} = 1.975 \times .808 = 1.596 \, IN^2$

$f_2 = 1.980 \times .866 = 1.715$

$g_2 = 1.980 \times .5 = .990$

$h_2 = 2.962 - .990 = 1.972$

$i_2 = 1.972 \times .577 = 1.138$

$K_2 = 1.715 - 1.138 = .577$

$A_{f_2 g_2} = \frac{1.715 \times .990}{2} = \frac{1.698}{2} \, IN^2$

$A_{h_2 i_2} = \frac{1.972 \times 1.138}{2} = \frac{2.244}{2} \, IN^2$

$A_{h_2 K_2} = 1.972 \times .577 = 1.138 \, IN^2$

	IN^3
$V_1 = [A_{1240} + 2A_{f_1 g_1} + 2A_{h_1 i_1} + 2A_{h_1 K_1}] \times c =$ $V_1 = [10.6 + 2.192 + 2.252 + 3.192] \times .698$	12.729
$V_2 = [A_{2240} + 2A_{f_2 g_2} + 2A_{h_2 i_2} + 2A_{h_2 K_2}] \times (c-e)$ $V_2 = [8.203 + 1.698 + 2.240 + 2.276] \times .198$	− 2.855
$V_3 = \frac{s^2}{2} 2K_1 = .2 \times .2 \times .808 =$	−.032
$\Sigma V =$	9.842

$W = \Sigma V \times \rho = 9.842 \times .098 = \underline{.965 \, LBS}$

F.H. BONWIT	5-21-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC. – HOUSING TRUSS (TUBULAR)

1t 2"ϕ TUBING RING; D=28" ON ℄; MATL: INVAR "36"; ρ=.291 #/IN³

ASSUME: BWG 16 WT=.065

d_o=2.00
2t = .13
d_i 1.87

D = 28

$V_1 = (d_o^2 - d_i^2).785 \times \pi D =$
$= (2.0^2 - 1.87^2) \times .785 \times \pi \times 28 =$ 34.50 IN³

QUANTITY: 2

W = V×ρ = 34.50 × .291 = 10.0 LBS EA.
ΣW = 20.0 LBS

2t 1"ϕ TUBING RING (EA.); D=28 ON ℄; MATL.: INVAR 36; ρ=.291 #/IN³

ASSUME: BWG 18 – WT=.049

D = 28

d_o = 1.00
2t .098
d_i = .902

$V_1 = (d_o^2 - d_i^2).785 \times \pi D =$
$= (1.0^2 - .902^2) \times .785 \times \pi \cdot 28 =$ 12.85 IN³

QUANTITY: = 4

W = V×ρ = 12.85×.291 = 3.73 LBS EA.
ΣW = 14.92 LBS

3t 1"ϕ TRUSS DIAGONAL ; MATL. INVAR 36 ρ=.291 #/IN³

DIAGONALS

TYP.	BAY	L	W (EA)	QUAN	ΣW
A	I	10.0	.426	2	.852
B	I	10.33	.44	10	4.40
C	II III IV	15.82	.673	36	24.30
D	V	20.07	.854	12	10.25
					Σ 39.802

ASSUME: BWG 18 – T=.049
BAY d_o = 1.0
d_i = .902

$W = (d_o^2 - d_i^2).785 \times 1.0 \times \rho = (1.0^2 - .902^2).785 \times 1.0 \times .291 = .0426$ #/IN

ΣW = 39.802 LBS

	LBS.
1t	20.0
2t	14.92
3t	39.802
Σ	74.722

TUBULAR TOTAL → 74.722

F. H. BONWIT — PREPARED BY — 5-23-68 DATE
CHECKED BY — DATE
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
REPORT NO.
PROJECT

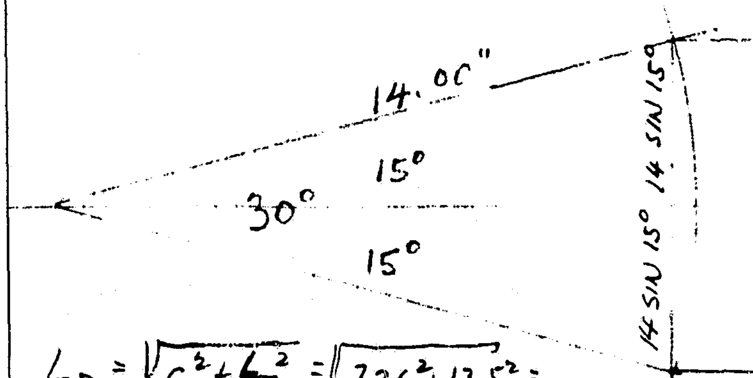
TITLE WEIGHT CALC - HOUSING TRUSS (TUBULAR)

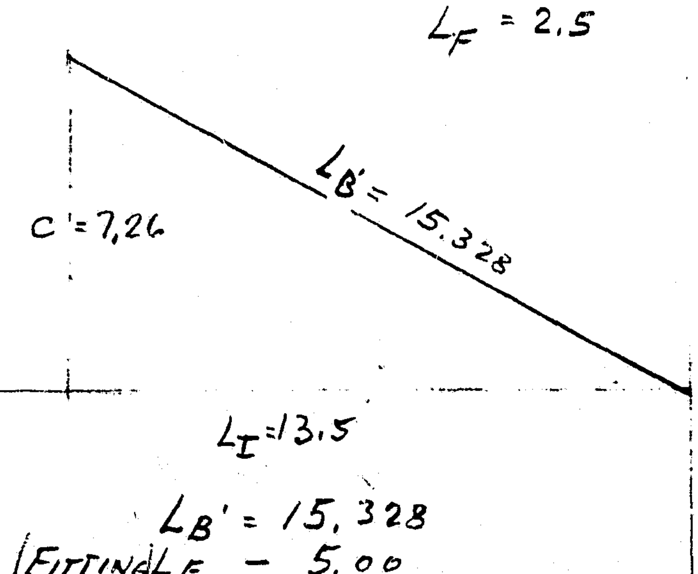
3t 1"φ TRUSS DIAGONAL - BAY I (CONT'D.)

$\frac{c}{2} = 14 \times \sin 15° = 14 \times .2588 = 3.63$

$c = 7.26$

$L_F = 2.5$





$L_B = \sqrt{c^2 + L_I^2} = \sqrt{7.26^2 + 13.5^2} =$

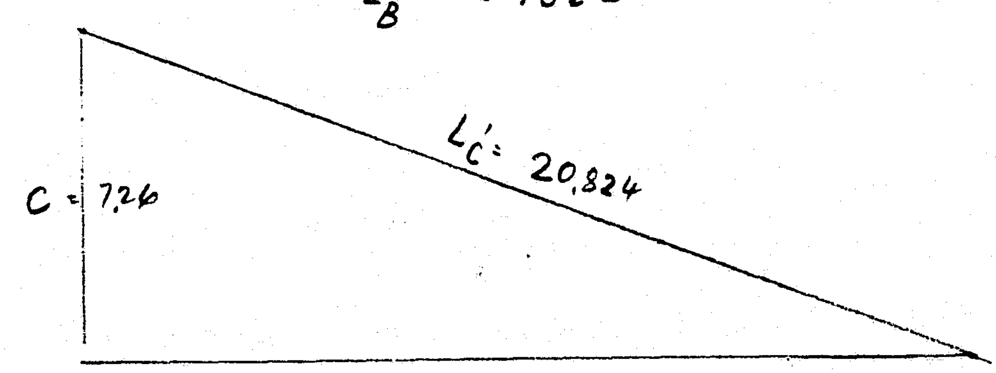
$L_B = 15.328$

BAY I

$L_B' = 15.328$

(2) (FITTING) L_F $- 5.00$

$L_B = 10.328$



$L_C = \sqrt{c^2 + L_{II}^2} = \sqrt{7.26^2 + 19.517^2} =$

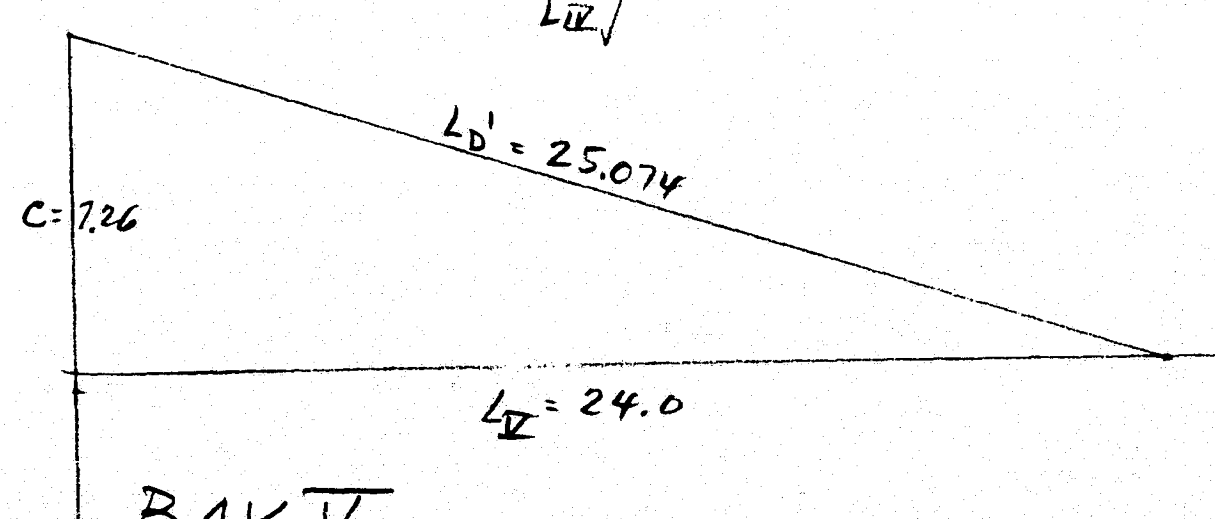
$L_C = 20.824$

$2L_F$ 5.00

$L_C = 15.82$

BAY II, III & IV

$\left.\begin{matrix} L_{II} \\ L_{III} \\ L_{IV} \end{matrix}\right\} = 19.517$



$L_D = \sqrt{c^2 + L_V^2} =$

$= \sqrt{7.26^2 + 24^2} =$

$L_D' = 25.074$

$2L_F$ $= 5.00$

$L_D = 20.07$

BAY V

CLASSIFICATION — JPL 0999-1-S APR 66

PAGE 25 OF ____

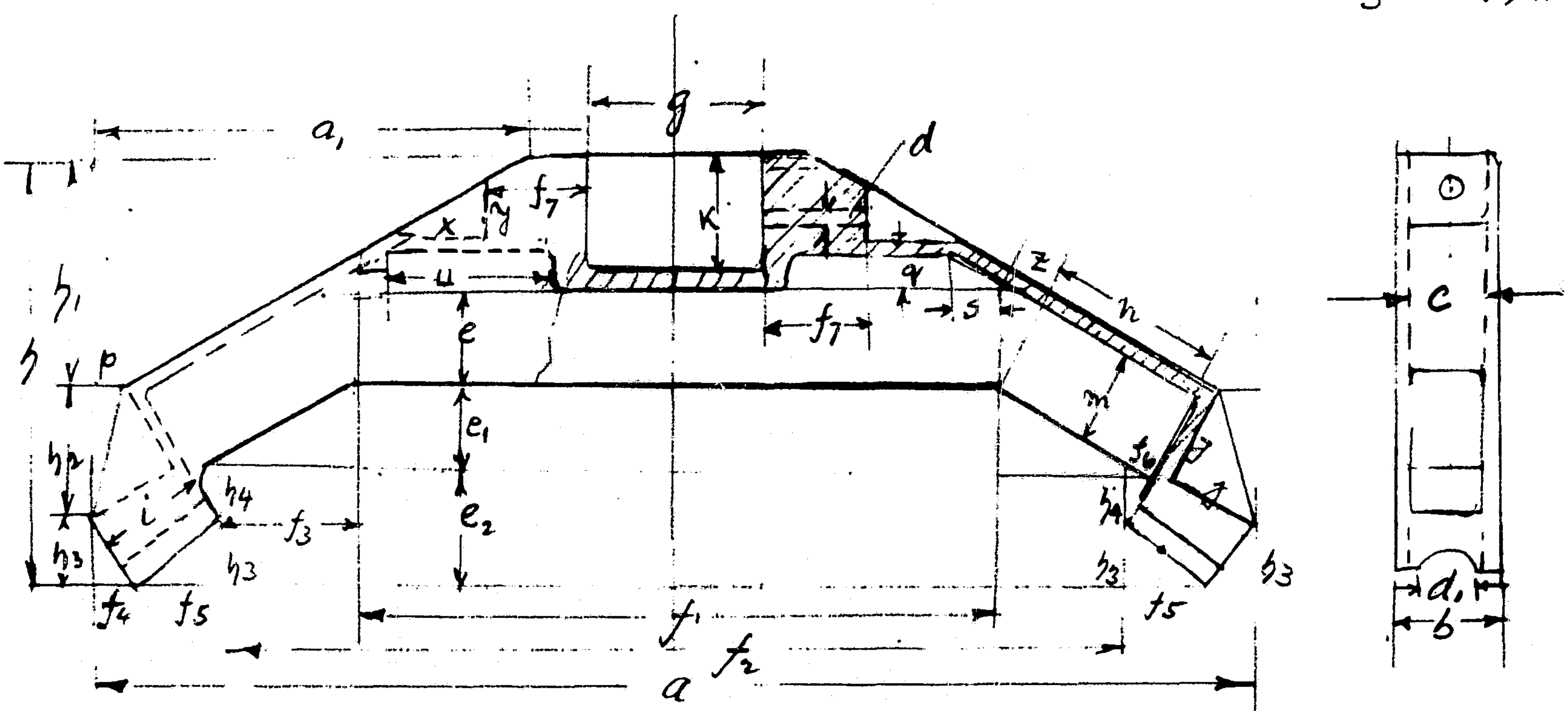
F. H. BONWIT	5-24-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC. – HOUSING TRUSS–SUSPENSION–PIVOT END

1 rq'd

PIVOT YOKE

MATL.: INVAR "36"
$\rho = .291 \#/IN^3$



a = 21.5
a₁ = 8.0
b = 2.0
c = 1.5
d = .312
e, = 1.75
f_1 = 12.0
f_2 = 16.6
f_3 = 2.3
f_4 = .6
f_5 = 1.5
f_6 = .5
f_7 = 2.0
g = 3.3
h = 8.0
h_1 = 4.2
h_2 = 2.6
h_3 = 1.2
h_4 = 1.0
d_1 = 1.0
i = 2.0
j = 1.75

K = 2.2
m = 1.75
n = 3.3
p = .6
q = 1.0
s = 1.0
t =
e_1 = 1.6
e_2 = 2.2
u = 3.0
x = 1.75
y = 1.0
z = .8

IN^3		
344.0	V_1	$a \times b \times h = 21.5 \times 2 \times 8$
−14.2	$-V_2$	$K \times g \times b = 2.2 \times 3.3 \times 2$
−111.4	$-V_3$	$[e_1 f_1 + e_2 f_2] b =$ $[1.6 \times 12.0 + 2.2 \times 16.6] 2$
−31.5	$-V_4$	$e \times f_1 \times c = 1.75 \times 12.0 \times 1.5$
−17.35	$-V_5$	$2(m \times n \times c) = 2 \times 1.75 \times 3.3 \times 1.5$
−9.0	$-V_6$	$2(q \times u \times c) = 2 \times 1 \times 3 \times 1.5$
−67.0	$-V_7$	$2\left(\frac{h_1 \times a_1 \times b}{2}\right) = 4.2 \times 8 \times 2$
−4.5	$-V_8$	$\frac{2x^2}{2} c = 1.75^2 \times 1.5$
−3.00	$-V_9$	$\frac{2xy}{2} \times c$ 1.75

IN^3		
−2.2	$-V_{10}$	$\frac{2z \times m}{2} \times c = .8 \times 1.75 \times 1.5$
−7.35	$-V_{11}$	$2\left(\frac{f_3 \times e_1 \times b}{2}\right) = 2.3 \times 1.6 \times 2.0$
−3.12	$-V_{12}$	$2\left(\frac{f_4 \times h_3}{2}\right) b = .6 \times 2.6 \times 2.0$
−3.6	$-V_{13}$	$\frac{2 f_5 h_3 \times b}{2} = 1.5 \times 1.2 \times 2.0$
−.6	$-V_{14}$	$2 h_4 \frac{f_6 \times b}{2} = .6 \times .5 \times 2.0$
−3.04	$-V_{15}$	$2(d^2 .785) f_7 = .762 \times 2 \times 2$
−3.12	$-V_{16}$	$\frac{2 h_2 \cdot p \cdot b}{2}$ 2.6 .6 2.0
−1.57	$-V_{17}$	$2\left(\frac{d_1^2 \cdot .785 \cdot i}{2}\right) = 2 \times 1 \times .785$

ΣV 61.15#

$W = \Sigma V \times \rho = 61.45 \times .291 = \underline{17.90 \text{ LBS.}}$

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONWIT — PREPARED BY — 5-27-68 DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO. ____

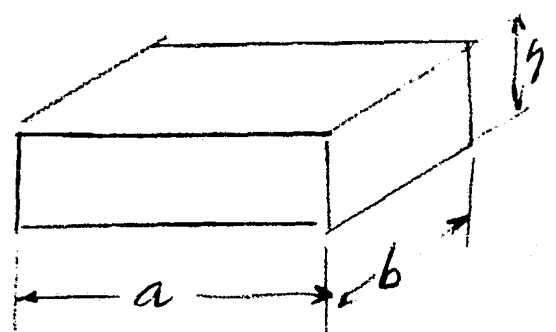
CHECKED BY ____ DATE ____ PROJECT ____

TITLE: WEIGHT CALC - HOUSING TRUSS-SUSPENSION-PIVOT END & SUMMARY

6tp

PILLOW BLOCK(S)

MATL. INVAR "36"



$a = 2.0;\ b = 2.0;\ h = 1.5$

	IN^3
$V_1 = a \times b \times h = 2.0 \times 2.0 \times 1.5 =$	6.0
$V_2 = d^2 .785 \times a = .312^2 \times .785 \times 2.0$	1.52
	4.48

$2W = \Sigma V \times \rho = 2 \times 4.48 \times .291 = \underline{2.61\ LBS}$

HOUSING TRUSS SUSPENSION

PIVOT END		WEIGHT - LBS	
1tp	PIVOT YOKE	17.90	
2tp	MOUNT CHANNELS (2)	3.40	
3tp	PIVOT BLOCK (2)	4.52	
4tp	PIVOT BOLT	1.73	
5tp	TIE BOLT	1.61	
6tp	PILLOW BLOCK (2)	2.61	
			31.77
1tf	TIE CHANNEL (2)	72.2	
2tf	I-BLOCK (2)	32.4	
3tf	TAPER BLOCK (2)	4.36	
4tf	YOKE TEE	24.80	
			133.76
	SUSPENSION TOTAL		165.53

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BONWIT — PREPARED BY — 5-24-68 — DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

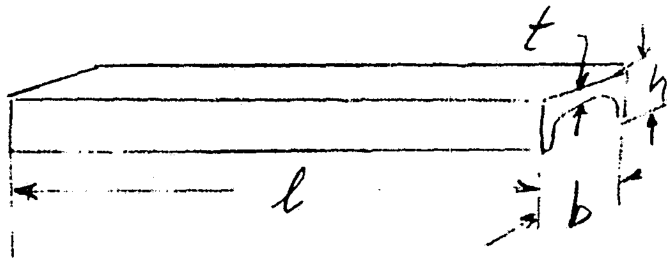
REPORT NO. ____

CHECKED BY ____ DATE ____ PROJECT ____

TITLE
WEIGHT CALC. — HOUSING TRUSS - SUSPENSION - PIVOT END

2tp. MOUNT CHANNEL(S) (RIGHT & LEFT)

MATL.: INVAR 36 $\rho = .291 \#/IN^3$



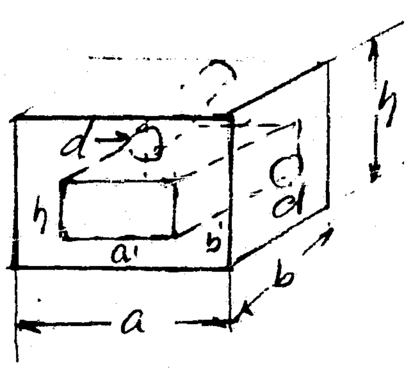
$b = 2.0$; $h = 1.0$; $l = 6.5$
$t = .25$

	IN^3
$V_1 = b \times h \times l = 2.0 \times 1.0 \times 6.5$	13.0
$V_2 : b' h' \times l = 1.5 \times .75 \times 6.5$	$-\sim 7.15$
ΣV	5.85

$2W = \Sigma V \times \rho = 2 \times 5.85 \times .291 = $ 3.40 LBS

3tp. PIVOT BLOCK(S)

MATL INVAR "36"
$\rho = .291$



$a = 3.0$; $b = 2.0$; $h = 2.5$
$a_1 = 2.0$ b_1 1.7 $h_1 = 1.0$

$d =$

	IN^3
$V_1 = a \times b \times h = 3.0 \times 2.0 \times 2.5$	15.0
$V_2 = a_1 \times b_1 \times h_1 = 2.0 \times 1.7 \times 1.0$	− 3.40
$V_3 = d^2 .785 \times a = .312^2 \times .785 \times 3.0$	− 2.29
$V_4 = d^2 .785 \times b = .312^2 \times .785 \times 2.0$	− 1.53
	7.78

$2W = \Sigma V \times \rho = 2 \times 7.78 \times .291 = $ 4.52 LBS

4tp. PIVOT BOLT

MATL. STEEL; $\rho = .283 \#/IN^3$

$d = .312$ $L = 8.0$

$V = d^2 \times .785 \times L = .312^2 .785 \times 8.$ | IN^3 6.1

$6.1 \times .283 = $ 1.73 LBS

5tp. TIE BOLT

MATL.: STEEL $\rho = .283 \#/IN^3$

$d = .312$ $L = 7.5$

$V\ d^2 .785 \times L = .312^2 \times .785 \times 7.5$

$5.7\ IN^3$

$\Sigma V \times \rho = 5.7 \times .283 = $ 1.61 LBS

F. H. BONIVIT — PREPARED BY
5-27-68 — DATE
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
REPORT NO.
CHECKED BY — DATE — PROJECT

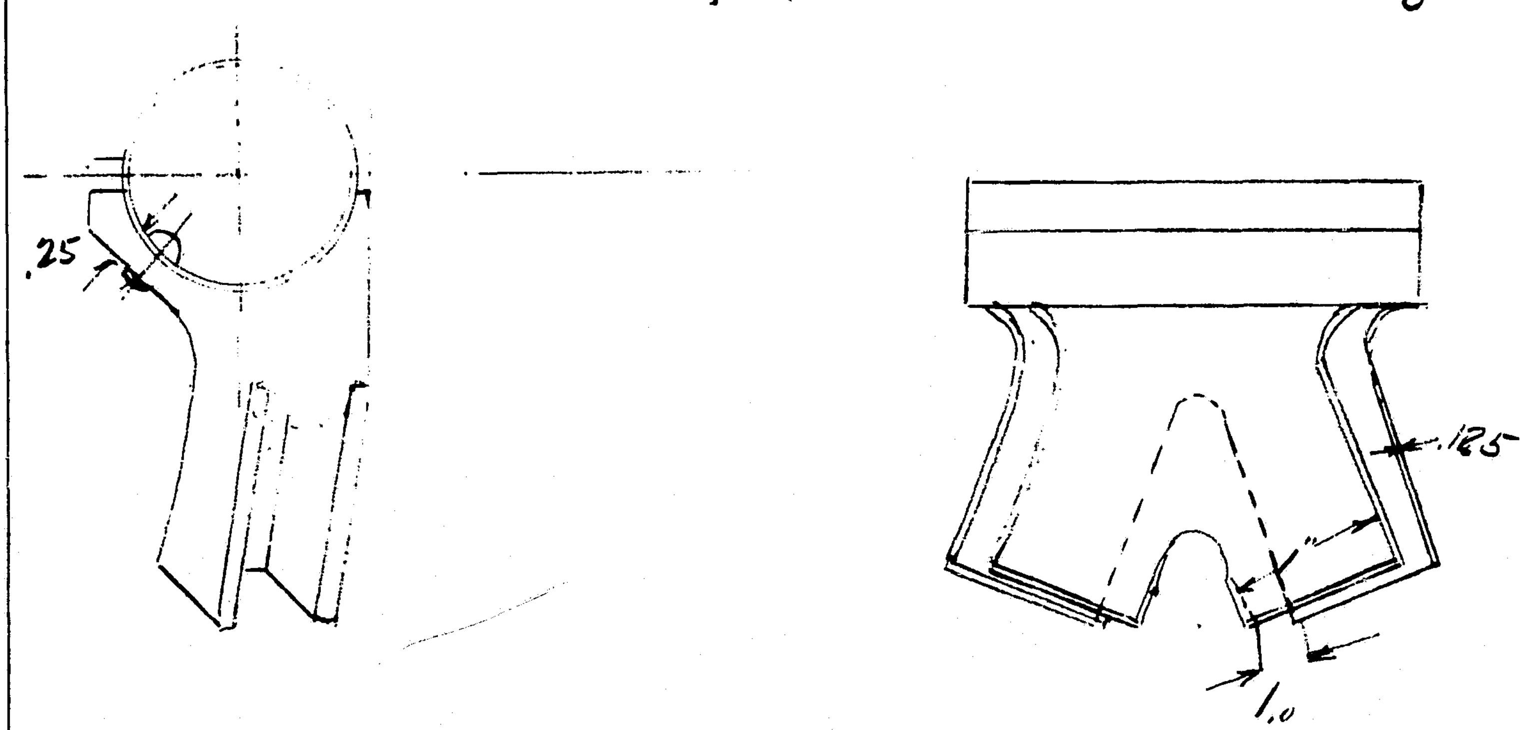
TITLE: WEIGHT CALC. - HOUSING TRUSS (TUBING)

SUMMARY

4t TUBE FITTINGS (DOUBLE)

REQ'D. (59)

MATL. INVAR "36" $\rho = .291\#/IN^3$



	IN^3
$V_1 = (4\times1.0\times1.0 + 2\times1.0\times1.0)\times.125 =$	.750
$V_2 = 1.25\times\pi\times.50\times2 =$ +	3.93
	4.680

$W = 4.680 \times .291 = \underline{1.365\ LBS\ EA.}$

(59) $W = 59 \times 1.365 = \underline{80.50\ LBS}$

5t TUBE FITTING (SINGLE)

REQ'D: (2)

	IN^3
$V_1 = (2\times1.0\times1.0 + 1\times1.0\times1.0)\times.125 =$	.375
$V_2 = 1.25\times\pi\times.5\times2 =$	3.930
	4.305

$W = 4.305 \times \rho = 4.305 \times .291 = \underline{1.25\ LBS\ EA.}$

(2) $W = 2\times1.25 = \underline{2.50\ LBS}$

HOUSING TRUSS (TUBING) — SUMMARY

		LBS
(1t→3t)	2-2"φ RING + 4-1"φ RING + 60-1" DIAGONALS:	74.72
(5t)	2-SINGLE TUBE FITTINGS	2.50
(4t)	58-DOUBLE " "	80.50
	→	157.72

CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY: F H BONWIT	DATE:	REPORT NO.:
CHECKED BY:	DATE:	PROJECT:

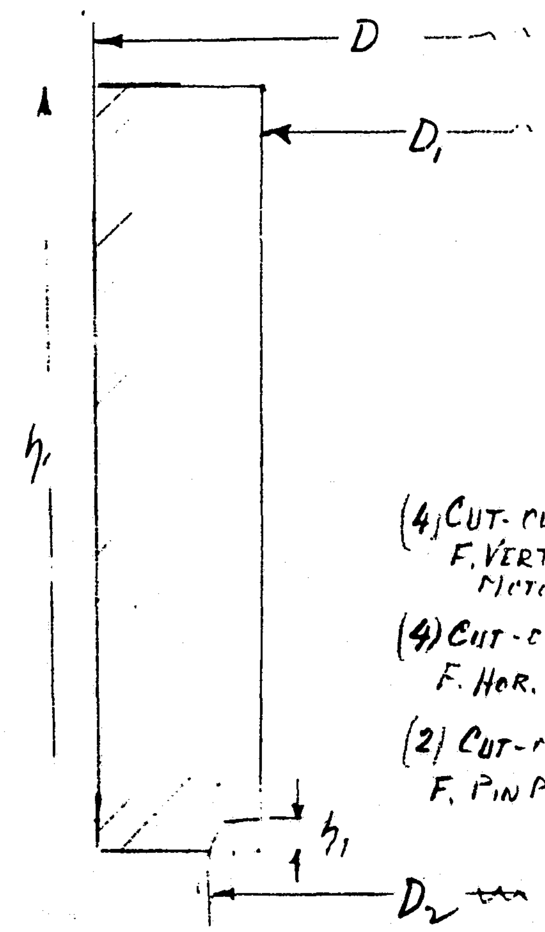
TITLE: WEIGHT CALC. – SECONDARY MIRROR ASSY. SYSTEM

CONT.'D FROM PAGE 15

REF. DWG {10026236, 10025023}

9a SPIDER RING

MAT'L.: 6061-T6 ALUMINUM $\rho = .098\,\#/IN^3$



$D = 29.0;\ D_1 = 26.0\ \ D_2 = 26.60$

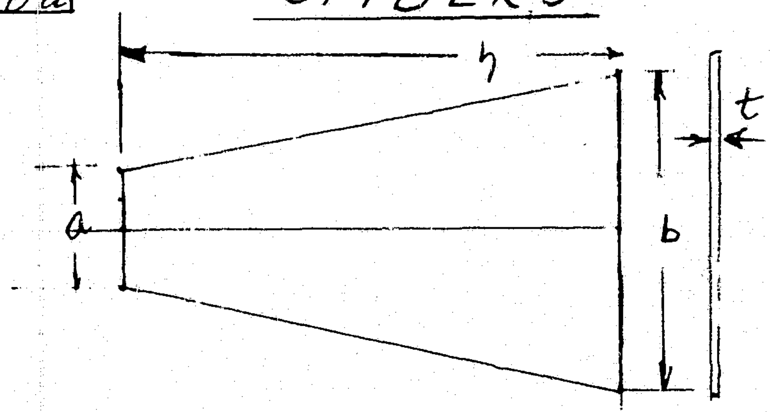
$h = 6.75;\ h_1 = .25$

	IN^3
$V_1 = (D^2 - D_1^2).785 \times h = (29.0^2 - 26.0^2).785 \times 6.75$	875.0
$V_2 = (D_2^2 - D_1)^2 .785 \times h_1 = (26.60^2 - 26.0^2).785 \times .25$	− 6.18
(4) CUT-OUTS F. VERT. MOTOR $V_3 = 4(3.5 + 2.75) \times 2.5 \times 1.5 =$	− 94.0
(4) CUT-OUT F. HOR. MOTOR $V_4 = [(11.5 \times 1.5 \times 1.0) + (4.5 + 6.0) \times 1.5 \times 1.5]4$	− 163.5
(2) CUT-OUTS F. PIN PULLERS $V_5 = 2(3.0 \times 4.0 \times 1.5) =$	− 36.0
(4) VERT. ROD HOLES $V_6 = 4 \times .15^2 .785 \times .25$	− .017
(4) HOR. ROD HOLES $V_7 = 4 \times 1.5^2 \times .785 \times 1 =$	− .07
ΣV	575.23

$W = \Sigma V \times \rho = 575.23 \times .098 = \underline{\underline{56.3\ LBS}}$

10a SPIDERS

MAT'L. INVAR "36"; $\rho = .291\,\#/IN^3$



$a = 2.5;\ b = 7.0;\ h = 11.0;\ t = .100$

$V = \frac{a+b}{2} h \times t = \frac{2.5+7.0}{2} 11.0 \times .10 = 5.24\ IN^3$

FOR (4) SPIDERS: $4 \Sigma V \times \rho = 4 \times 5.24 \times .291 = \underline{\underline{6.09\ LBS}}$

11a

5 FEET OF .25ϕ TUBING, .030 WT. MAT'L. STL. STL.: $\rho = .283\,\#/IN^3$

$\Sigma V = (.25^2 - .19^2) \times 12 \times 5 \times .785 = 1.245\ IN^3;\ W = \Sigma V \times \rho = 1.245 \times .283 = \underline{\underline{.353\ LBS}}$

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BONWIT	5-28-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC. – SECONDARY MIRROR ASSY SYSTEM. (CONT'D.)

E DENOTES ESTIMATE

COMPONENTS

			TOTAL WEIGHTS
12a 1. (4)	VERT. MOTOR & GEAR CASE	12 OZ. OR .5 LBS EA. –	2.0
2. (4)	HORIZ. MOTOR & GEAR CASE	12 OZ OR .5 LBS EA –	2.0
3. (8) E	COUPLING	1 OZ OR .063 LBS EA. –	.50
4. (8) E	BALL SCREW ASSY.	6 OZ OR .375 LBS EA –	2.99
5. (8) E	FLEXIBLE ROD	2 OZ OR .125 LBS EA.	1.0
6. (8) E	FLEXIBLE JOINT ASSY.	5 OZ OR .313 LBS EA –	2.5
7. (2) E	CARTRIDGE ACTUATED PIN PULLER	4 OZ OR .25 LBS EA	.5
8. (2) E	SUPPORT PAIRS FOR ITEM (12a7)	1 OZ OR .063 LBS EA.	.125
(2)	LOCKING STRAP: 4 × 1.0 × .25 } MAT'L. INVAR; ρ = .291	.291 LBS. EA.	.582
(2)	" " 2 × 1.0 × .25 }	.146 LBS EA	.291

$\Sigma W = 12.488$

FOR SUMMARY OF SECONDARY MIRROR ASSY. – SEE PAGE 15

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. Schmidt 5-29-68 — PREPARED BY / DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO. ___

CHECKED BY ___ DATE ___ PROJECT ___

TITLE WEIGHT CALC. - ELECTRICAL & ELECTRONICS ©

[COPIED FROM "WEIGHTS SUMMARY"]

1e	ELECTRONICS - TV	18.0 LBS
2e	ELECTRONICS - P.S	10.0 "
3e	SWITCHES	1.0 "
4e	ELECTR HARNESS & CONNECTORS	15.0 "
5e	SPOTTING SCOPE ASSEMBLY	20.0 "
		64.0 LBS

CLASSIFICATION

F.H. BONWIT
PREPARED BY

5-29-68
DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO

CHECKED BY

DATE

PROJECT

TITLE WEIGHT - CALC. - CAMERA-VIDICON CLUSTER & CAM [COPIED FROM "WEIGTS SUMMARY"]

1c	ACCESSORIES	18.3 LBS
2c	BASE PLATE	10.0 "
3c	HOUSING & ADAPTER	6.0 "
4c	MOTORS & GEARS	2.0 "
5c	FOCUS TRACK	3.2 "
6c	ALIGNMENT SENSOR ASSY	10.0 "
7c	VIDICON ASSEMBLIES (3)	15.0 "
8c	PIN PULLERS (2)	2.0 "
	MISCELANEOUS HARDWARE	10.0 "
		176.5 LBS

CLASSIFICATION

JPL 0999-1-S APR 66

F. H. BONWIT — PREPARED BY — 5-29-68 DATE

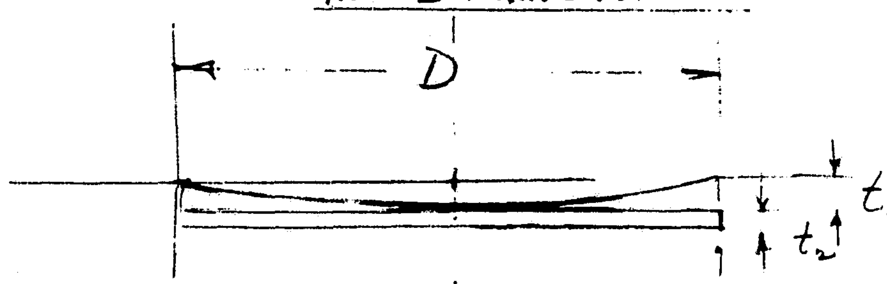
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO.

CHECKED BY — DATE — PROJECT

TITLE: WEIGHT CALC. – HEAT DUMP MIRROR SYSTEM

1W. HEAT DUMP MIRROR AND BACKING PLATE — MATL. 6061-T6 $\rho = .098$



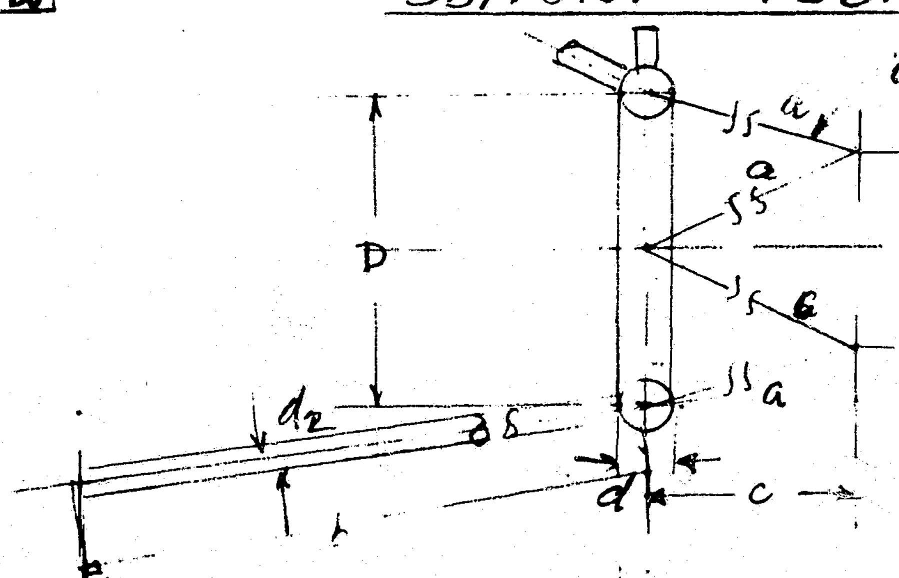
$t_1 = .40 \quad t_2 = .25$

$D = 7.100$

$$V = D^2 .785(.6t_1 + t_2) = 7.1^2 \times .785(.6 \times .40 + .25) = 19.40\,\text{IN}^3$$

$$\Sigma 1 \quad W = \Sigma V \times \rho = 19.40 \times .098 = \underline{\underline{1.91\text{ LBS}}}$$

2W SUPPORT TUBING ($3/8''\phi$ & $1/4''\phi$) MATL.: 6061 AL. $\rho = .098$



$a = 2.107$ — $c = 1.85$, $b = 5.0$

$D = 2.8$;

$d = .375 \quad d_2 = .25$

$d_1 = .277 \quad d_3 = .152$

$V_{3/8} = (d^2 - d_1^2).785 \times D\pi$

	IN^3
$V_{3/8} = (d^2 - d_1^2).785 \times D\pi = (.375^2 - .277^2).785 \times 2.8\pi =$	.44
$V_{1/4} = (d_2^2 - d_3^2).785 \times L = (.25^2 - .152^2).785 \times 22.56 =$	.698
ΣV	1.138

WT = .049 FOR 3/8" & 1/4" TUBING

$1/4\phi$ TUBING: $5.0 + .2 + .5 + 8(2.107) = 22.556 = L$

$$W = \Sigma V \times \rho = 1.138 \times .098 = \underline{\underline{.1115\text{ LBS}}}$$

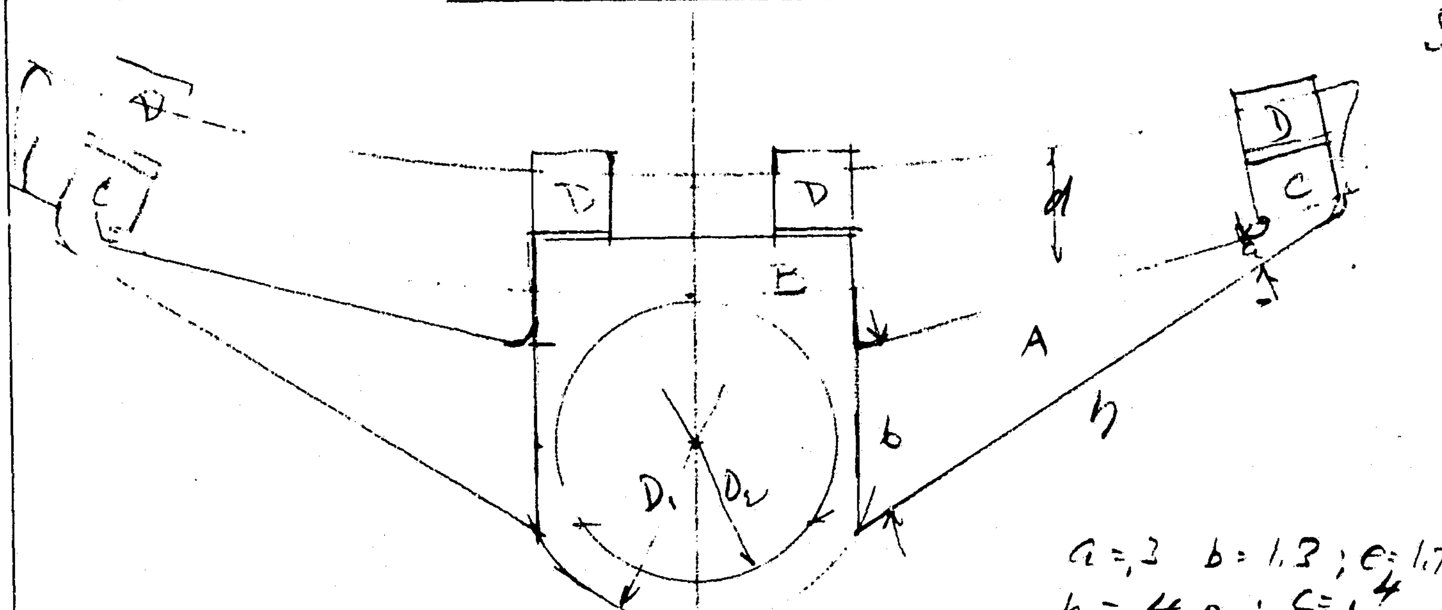
CLASSIFICATION — JPL 0999-1-S APR 66

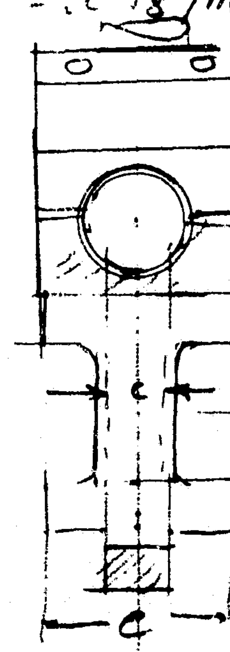
F.N. Benoit — PREPARED BY | 5-29-68 — DATE | **JET PROPULSION LABORATORY** CALIFORNIA INSTITUTE OF TECHNOLOGY | REPORT NO.

CHECKED BY | DATE | PROJECT

TITLE WEIGHT CALC. – HEAT DUMP MIRROR SYSTEM

3W MIRROR SUPPORT YOKE — MATL. 6061-T6 ALUM. $\rho = .098^{\#}/IN^3$





$a = .3$ $b = 1.3$; $e = 1.7$
$h = 4.0$; $c = .4$
$D_1 = 1.6$; $D_2 = 1.2$

$A_A = \frac{a+b}{2} h = \frac{.3+1.3}{2} \times 4 = 3.2\ IN^2$

$A_B = (2.8 \times 2.4) - (2.4^2 .785).60 = 4.01\ IN^2$

$A_C = (.55 \times .55) \times 2 = .3025 \times 2 = .1444$

	IN^3
$V_1 = 2A_A \times c = 2 \times 3.2 \times .4$	2.56
$V_2 = (D_1^2 - D_2^2).785 \times \frac{2\pi}{3} = (1.6^2 - 1.2^2).785 \times 2.09$	1.84
$V_3 = A_B \times e = 4.01 \times 1.7$	6.82
$V_4 = (A_C \times e) - \frac{d^2 .785}{2} = 1.44 \times 1.7 - \frac{(1.0).785}{2}$	1.655
$\Sigma V =$	12.875

$W = \Sigma V \times \rho = 12.875 \times .098 = \underline{\underline{1.26\ LBS}}$

4W HALF CLAMP(S) — MATL. 6061-T6 AL. $\rho = .098$

$A_D = .6 \times .6 = .36\ IN^2$

$V = A_D \times e - \frac{d^2 .785}{2} = .36 \times 1.7 - \frac{1.0(.785)}{2} = .219\ IN^3$

(4) HALF CLAMPS: $W = 4V \times \rho = 4 \times .219 \times .098 = \underline{\underline{.857\ LBS}}$

CLASSIFICATION

JPL 0999-1-S APR 66

F H B NIUIT	5-29-68	JET PROPULSION LABORATORY	
PREPARED BY	DATE		REPORT NO.
		CALIFORNIA INSTITUTE OF TECHNOLOGY	
CHECKED BY	DATE		PROJECT

TITLE WEIGHT CALC. - HEAT DUMP MIRROR SYSTEM SUMMARY

		WEIGHT - LBS	
1 W	HEAT DUMP MIRROR	1.91	
2 W	SUPPORT TUBING	.112	
3 W	MIRROR SUPPORT YOKE	1.26	
4 W	HALF CLAMPS	.857	
		TOTAL	4.139

CLASSIFICATION

JPL 0999-1-S APR 66

F.H. BONIWIT — PREPARED BY — 5-29-68 — DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

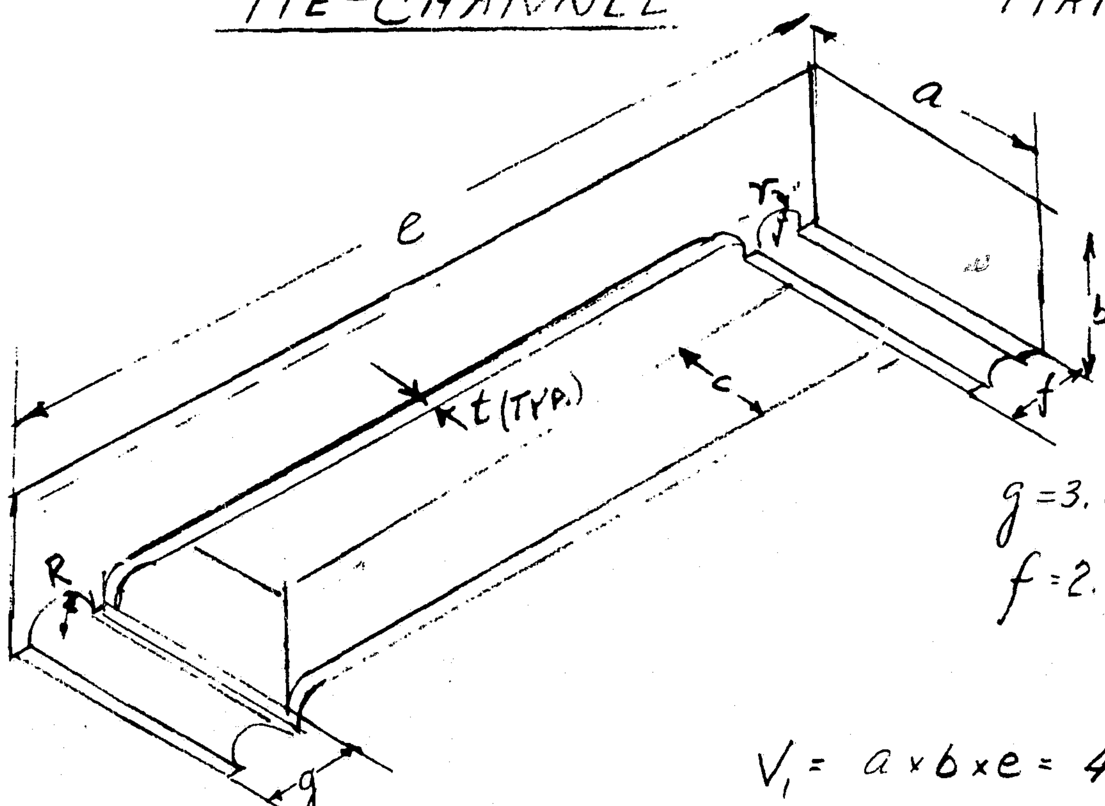
REPORT NO.

CHECKED BY — DATE — PROJECT

TITLE: WEIGHT CALC. - HOUSING TRUSS - SUSPENSION - FIXED END

$\boxed{17f}$ TIE-CHANNEL

MATL.: INVAR "36"; $\rho = .291\ ^{\#}/_{IN^3}$



$a = 4.0$
$b = 2.7$
$c = 2.0$
$e = 26.5$
$g = 3.0$
$f = 2.0$
$R = 1.0$
$r = .5$
$t = .5$

IN^3

$V_1 = a \times b \times e = 4.0 \times 2.7 \times 26.5 = 286.0$

$V_2 = (b-c-t) \times a \times (e-f-g) = (2.7-2.0-.5) \times 4.0 \times (26.5-2.0-3.0) = -17.2$

$V_3 = (e-f-g)(a-2t) \times c = 21.5(4.0-1.0) \times 2.0 = -129.0$

$V_4 = \pi(R^2+r^2)\,a = \pi(1.0^2+.5^2) \times 4.0 = -15.7$

(2) REQ'D.

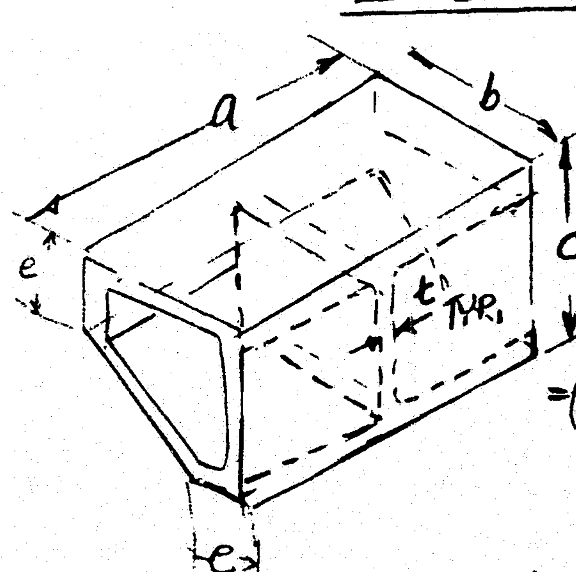
124.1

$W = \Sigma V \times \rho = 124.1 \times .291 = \underline{\underline{36.1\ LBS\ EA.}}$

$\boxed{2tf}$ I-BLOCK

MATL.: INVAR "36"; $\rho = .291\ ^{\#}/_{IN^3}$

$a = 4.0;\ b = 5.0\ \ c = 5.5;\ e = 2.0$
$t = .5$



IN^3

$V_1 = a \times b \times c = 4.0 \times 5.0 \times 5.5 = 110.00$

$V_2 = (a-t)\left[(c-2t)(b-2t) - \frac{(c-2t-e) \times (b-2t-e)}{2}\right]$

$= (4.0-.5)\left[(5.5-1.0)(5.0-1.0) - \frac{(5.5-1.0-2.0) \times 5.0-1.0-2.0}{2}\right] = -54.30$

$\Sigma V = 55.70$

(2) REQ'D

$W = \Sigma V \times \rho = 55.70 \times .291 = \underline{16.2\ LBS}$

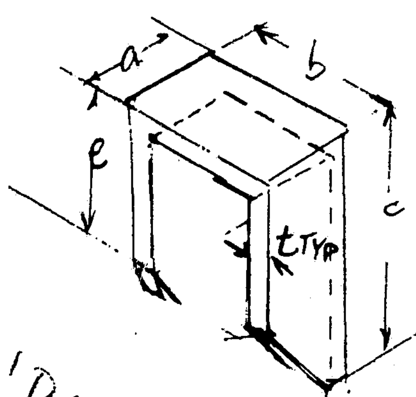
CLASSIFICATION

F.H. Bcnwit — PREPARED BY — 5-29-68 DATE
CHECKED BY — DATE
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO. ____
PROJECT ____

TITLE: WEIGHT CALC — HOUSING TRUSS - SUSPENSION - FIXED END

3 t7 TAPER BLOCK — MATL.: INVAR 36; $\rho = .291\ \#/IN^3$



(2) REQ'D.

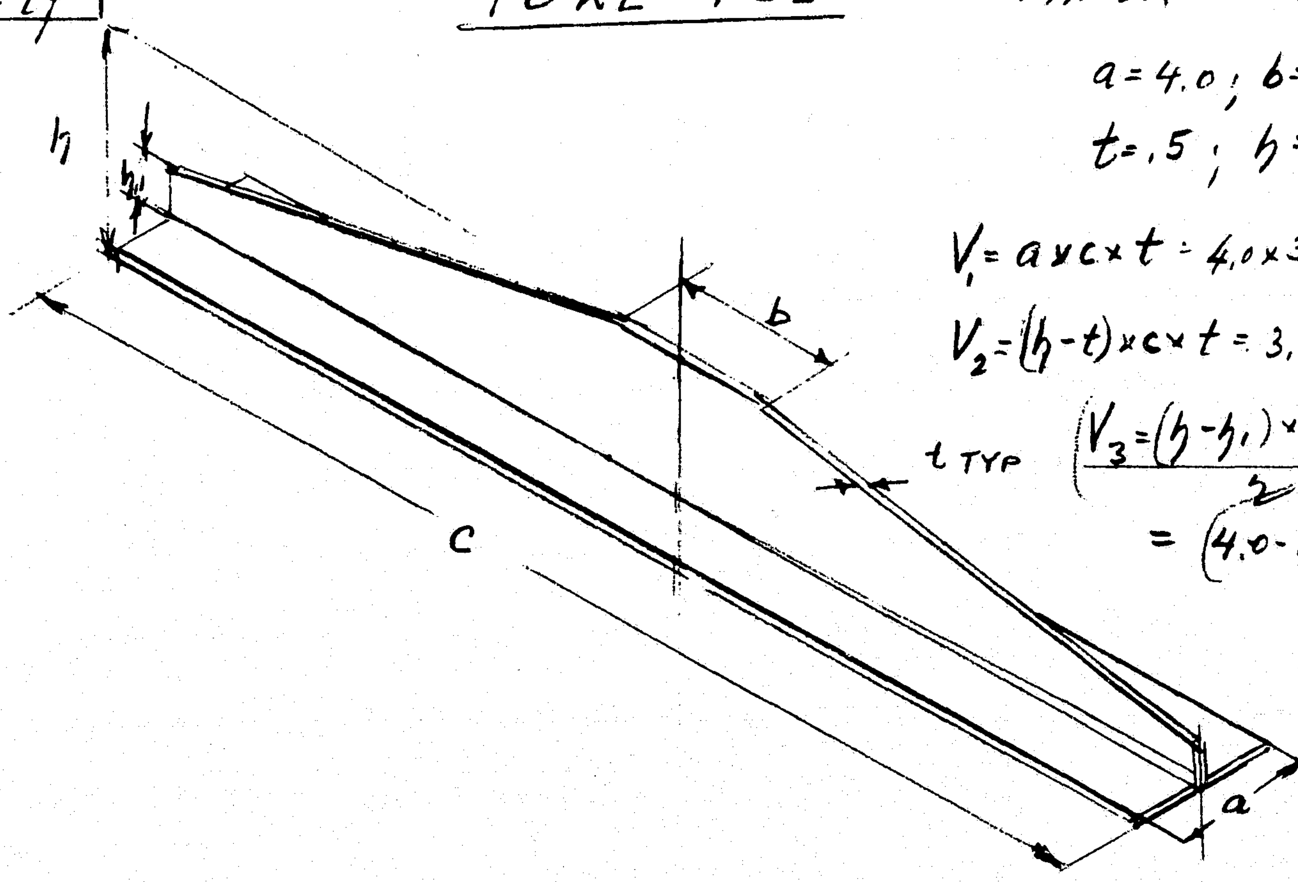
$a = 1.8;\ b = 2.0;\ c = 3.5;\ e = 2.4\quad t = .5$

	IN^3
$V_1 = a \times b \times c = 1.8 \times 2.0 \times 3.5$	12.6
$V_2 = (b-2t) \times (e-t)(a-t)$ $= (2.0-.5) \times (2.4-.5)(1.8-.5) =$	− 3.7
$V_3 = \frac{(c-e) \times (a-t) \times b}{2} = \frac{(3.5-2.4) \times (1.8-.5) \times 2.0}{2}$	− 1.4
ΣV	7.5

$W = \Sigma V \times \rho = 7.5 \times .291 = \underline{\underline{2.18\ LB}}$

4 t7 YOKE TEE — MATL.: INVAR "36"; $\rho = .291\ \#/IN^3$

$a = 4.0;\ b = 4.0;\ c = 31.0$
$t = .5;\ h = 4.0;\ h_1 = 1.7$



	IN^3
$V_1 = a \times c \times t = 4.0 \times 31.0 \times .5 =$	62.0
$V_2 = (h-t) \times c \times t = 3.5 \times 31.0 \times .5$	54.3
	116.3
$\left(V_3 = (h-h_1) \times \frac{c-b}{2}\right)\frac{2}{2}$ $= (4.0-1.7) \times \frac{27}{2} =$	− 31.0
ΣV	85.3

$W = \Sigma V \times \rho = 85.3 \times .291 = \underline{24.8\ LBs}$

CLASSIFICATION

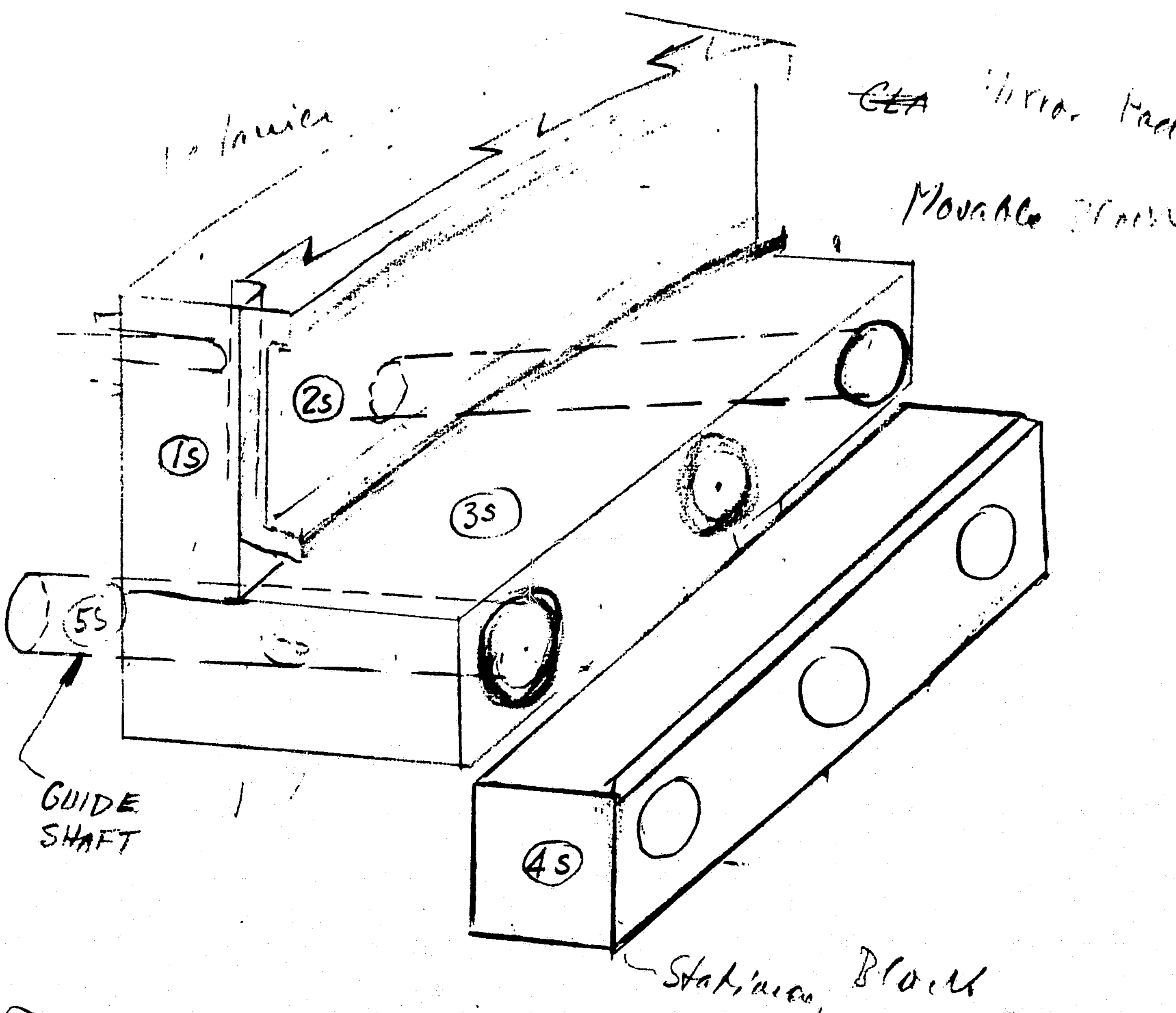
JPL 0999-1-S APR 66

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.

CHECKED BY | DATE | PROJECT

TITLE



DENSITY: $\#/IN^3$

STEEL : .283

ALUM. : .098

INVAR: .291

CLASSIFICATION

JPL 0999-1-S APR 66

APPENDIX C

PRELIMINARY DESIGN LOADS FOR THE ATM TELESCOPE

APPENDIX C

PRELIMINARY DESIGN LOADS FOR THE ATM TELESCOPE

B.K. Wada

Various design loads for preliminary analysis of the ATM Telescope are currently used for its design. The objective of the I. O. M. is to document the current estimate of the levels for preliminary design.

A review of the document, "Environmental Design and Qualification Test Criteria for Apollo Telescope Mount Components" 50MOZ408A Revision A, February 1, 1968 indicated that the low frequency sinusoidal vibration loads are the most severe. The vibration levels applicable to ATM are listed in Appendix B. I. E. title "Vibration Criteria for components mounted to ATM Canister Spar Assembly, total weight of components greater than 600 pounds but less than 800 pounds" on page 49. As a first estimate, without a dynamic analysis, an equivalent quasi-static load is determined.

A reasonable estimate of structural damping for the structure is 2 percent of critical damping. Damping values have ranged from 1/2 percent to 5 percent on various spacecrafts dependent on the mode and amplitude of vibration.

For a 2 percent damping value, the structural amplification Q is obtained from,

$$Q = \frac{1}{2\mu} = \frac{1}{2(.02)} = 25.$$

In the flight axis direction, the acceleration is estimated to be 2. 3 x 25 = 57. 5 g's and in the lateral axis 2. 0 x 25 = 50 g's.

For preliminary design purpose, 50 g's quasi-static loads in three orthogonal directions are used. The loads are assumed to act independently in the three orthogonal directions.

Better estimates of the loads will be obtained upon completion of the dynamic analysis and after the vibration tests. The true loads can't be evaluated until after the ATM Telescope vibration tests and the total ATM systems test at MSFC.

APPENDIX D

PRELIMINARY STRESS ANALYSIS OF HOUSING TRUSS STRUCTURE

H. H. Mc
PREPARED BY

6-25-68
DATE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

REPORT NO

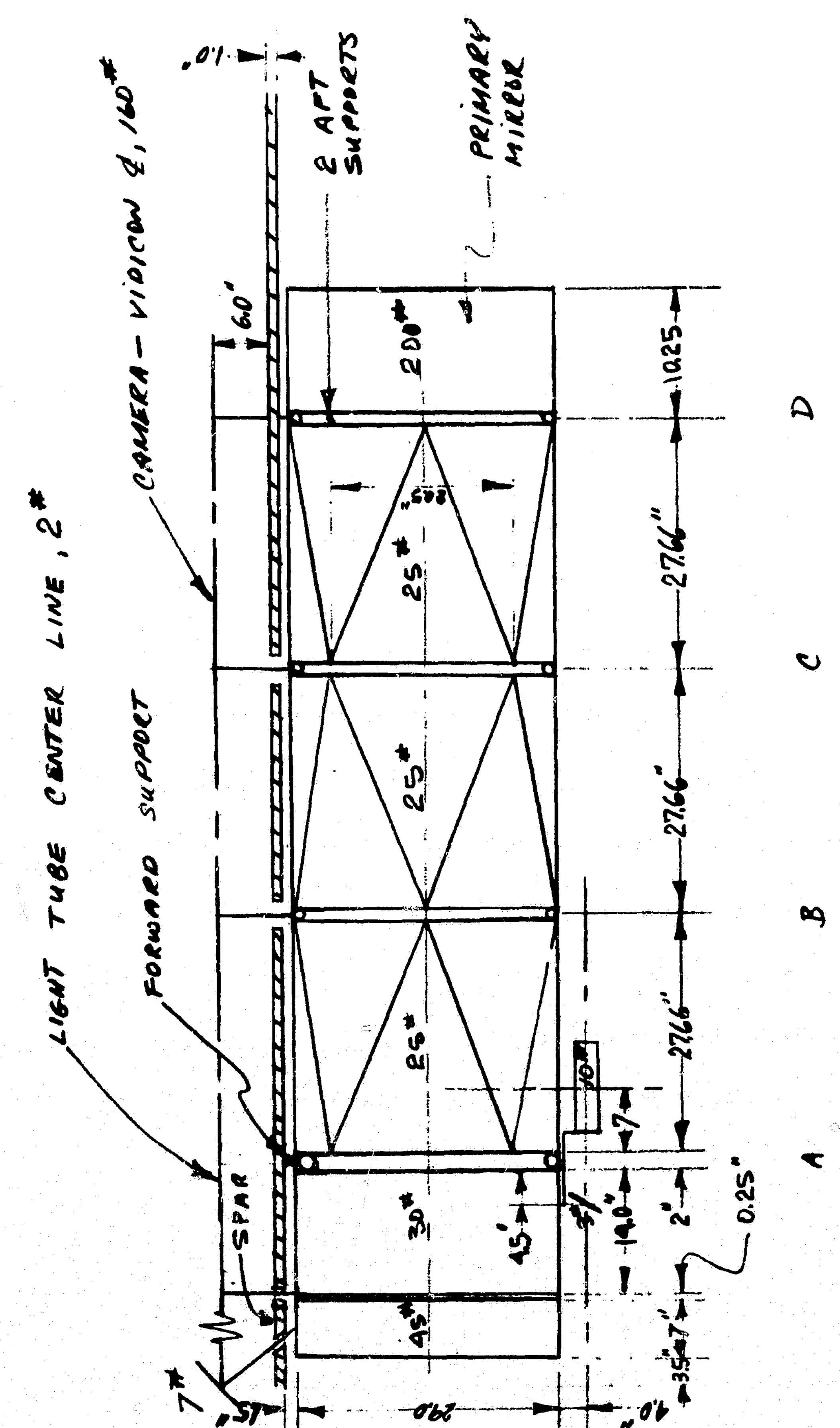
CHECKED BY

DATE

PROJECT

TITLE APPENDIX D

PRELIMINARY STUDY OF ATM. TELESCOPE FRAME STRUCTURE



JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY	DATE	REPORT NO.
CHECKED BY	DATE	PROJECT

TITLE

10 G <u>AXIAL LOAD</u>

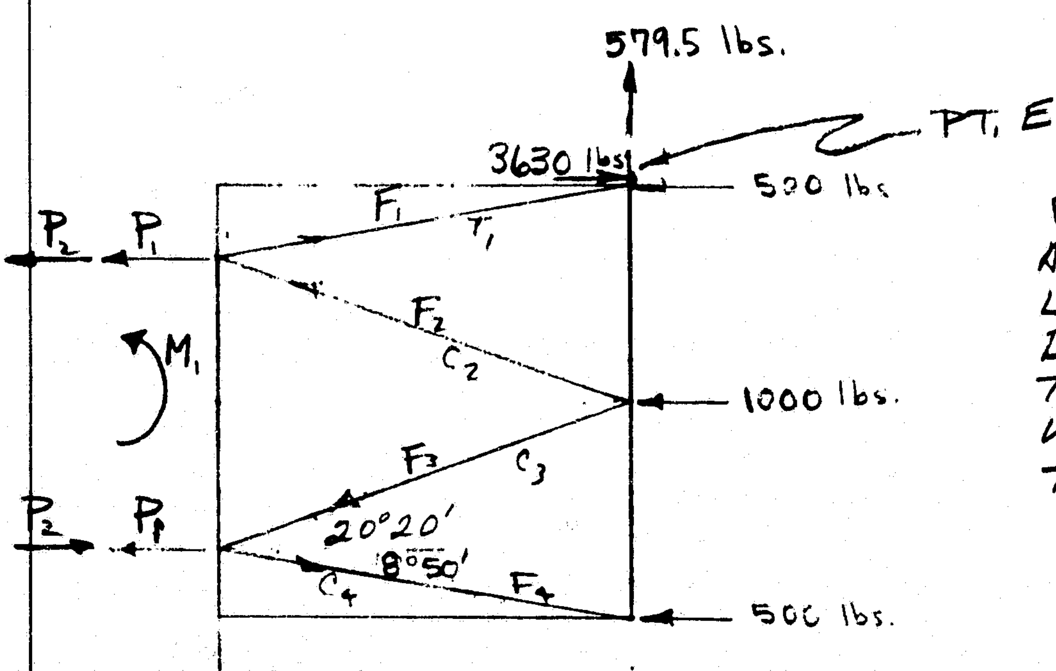
TAKE MOMENTS ABOUT FORWARD SUPPORT

$$M = 10[(200+25+25+25+30+45)16.0 + (34.5)(13.0) - (7+2+160)(7)]$$
$$= (5600 + 448.5 - 1183.0)10 = 48655 \text{ in-lbs.}$$

REACTION R AT AT AFT SUPPORTS

$$R = \frac{48655}{3(27.66)+1.0} = \frac{48655}{83.98} = 579.5 \text{ lbs.}$$

NEXT CONSIDER STRUCTURE BETWEEN C – D



FOR PRELIMINARY ANALYSIS ASSUME ALL THE FORWARD LOAD ABOVE SPAR IS DIRECTLY TRANSFERED TO THE AFT SUPPORT WITHOUT PASSING THROUGH THE BRACINGS.

WT. BELOW SPAR = $200 + 3\times25 + 30 + 45 + 10 + 3 = 363$

10 G. FOR HINGE SHEAR = 3630 lb.

THUS

$$2P_1 = 3630 - 2000 = 1630$$

$$\boxed{P_1 = 815 \text{ lbs.}}$$

CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

NEXT TAKE MOMENTS ABOUT PT. E

$$M_1 = 2000(14.5) + (1630)(14.5) - (579.5)(27.66)$$
$$= 36,604 \text{ in-lbs}$$

NOW THIS M_1 HAS TO BE TAKEN BY THE TRUSS

$$P_2 = \frac{36604}{20.5} = 1785.6 \text{ lbs.}$$

NEXT SOLVE FOR THE FORCES IN THE MEMBERS

$$F_1 \cos 8°50' = 3630 - 500 = 3130 \text{ lbs.}$$

$$F_1 = \frac{3130}{.9881} = 3167.7 \text{ lbs.}$$

T_1 = ACTUAL LOAD IN EACH BRACING

$$T_1 = \frac{3167.7 \text{ lbs.}}{2 \cos 20°20'} = \frac{3167.7}{2(.9377)} = \boxed{1689.0 \text{ lbs.}}$$

$$-F_1 \cos 8°50' + 815 + 1785.6 = F_2 \cos 20°20'$$

$$F_2 = \frac{-3130 + 2600.6}{.9377} = \frac{-529.6}{.9377} = -564.8 \text{ lbs}$$

C_2 = ACTUAL LOAD IN THIS MEMBER

$$= \frac{-564.8}{2 \cos 8°50'} = \frac{-564.8}{1.9762} = \boxed{-285.8 \text{ lbs.}}$$

$$F_3 \cos 20°20' = -F_2 \cos 20°20' - 1000 = 529.6 - 1000$$

$$F_3 = \frac{-470.4}{.9377} = -501.7 \text{ lbs.}$$

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

$$C_3 = \frac{-501.7}{2\cos 8^\circ 50'} = \frac{-501.7}{1.9762} = \boxed{-253.9 \text{ lbs.}}$$

$$F_4 \cos 8^\circ 50' = -F_3 \cos 20^\circ 20' + 815 - 1785.6$$

$$= 470.4 + 815 - 1785.6$$

$$= -500.2 \text{ lb.}$$

NOTE THIS VALUE SHOULD BE -500, ITS OFF BY 0.2 lb. BECAUSE OF THE ROUNDING OFF OF FIGURES TO ONE DECIMAL PLACE.

$$F_4 = \frac{-500.2}{.9881} = -506.2 \text{ lb.}$$

$$C_4 = \frac{-506.2}{2\cos 20^\circ 20} = \frac{-506.2}{1.8754} = \boxed{-269.9 \text{ lbs.}}$$

NOTE: THE F'S ARE THE FORCES IF STRUCTURE WAS 2-D. THE T & CS ARE THE FORCES IN THE 3-D STRUCTURE.

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

3-G SIDE LOAD

FOR THE SIDE LOAD, THE REACTIONS ARE EQUIVALENT TO THE COMBINATION OF THE DIRECTLY SUPPORTING ON THE CENTERLINE AND A ROTATION ABOUT THE CENTERLINE. LIKEWISE WITH THE STRESSES IN THE MEMBERS.

FOR CTR. LINE SUPPORT, TAKE MOMENTS ABOUT SUPPORT AT POINT A

$$7(3)(25.75)+(45)(3)(18.75)+(30)(3)(8.0)+3(3)(5.5)$$
$$=3(25)3(27.66+13.83+1.0)+(10)(3)(8)+(200)(3)(82.98+5.13+1)$$
$$+(160)(3)(56.38+13.83)+2(3)(27.66+1)-R_D(82.98+1)$$

$$R_D=\frac{180.25+843.75+256.5-3186.75-80-17824.0-11224.0-57.32}{1/3(83.98)}$$

$$=\frac{(-31081.57)3}{83.98}=\boxed{1110.3\text{ lbs.}}$$

THUS THE SHEAR ON EACH OF THE AFT HINGE IS $\frac{1110.3}{2}=\boxed{555.2\text{ lbs.}}$

THE TOTAL SIDE LOAD:

$$=(200+75+75+160+2+7+13)3=\underline{1596\text{ lbs.}}$$

CLASSIFICATION

JPL 0999 -5 APR 66

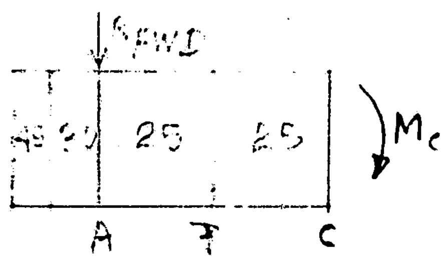
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

THUS $R_{FWD} = 1596 - 1110.3 = \boxed{485.7 \text{ lbs.}}$

HORIZONTAL SHEAR



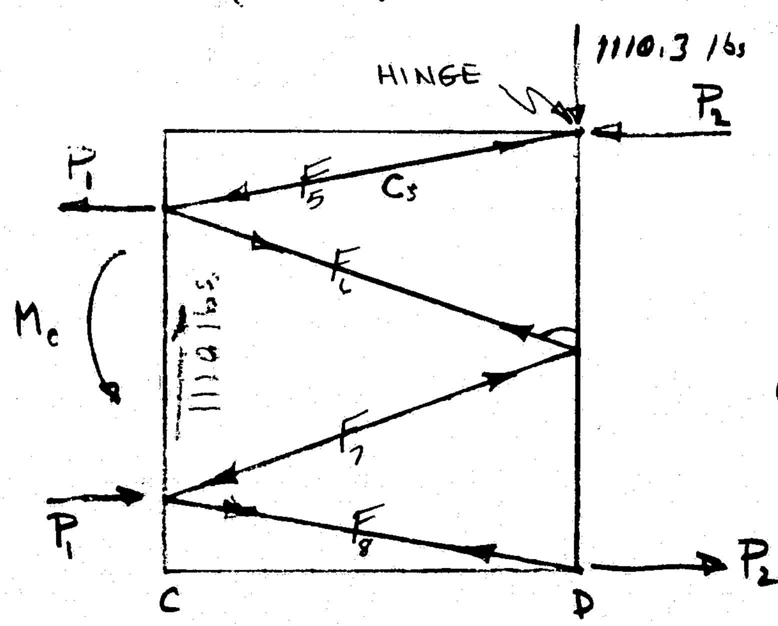
TAKE THE LEFT PART OF THE STRUCTURE AS A FREE BODY AND TAKE MOMENTS ABOUT A.

$(45)([illegible])(18.75) + (30)(3)([illegible]) + (3)(3)(5.5) + (7)(3)(25.75)$

$= (3)(25)(14.83) + 3(25)(42.49) + (10)(3)(8) + 2(3)(10) - M_c$

$\frac{1}{3} M_c = 252.75$ in - lbs.

$M_c = 758.75$ in - lbs



HORIZONTAL SECTION

$P_1 = \frac{M_c}{20.5} = \frac{758.75}{20.5} = 37.01 \text{ lbs}$

NEXT TAKE MOMENTS ABOUT HINGE:

$(1110.3)(27.66) - M_c = (29.0) P_2$

$P_2 = \frac{30,710.90 - 758.75}{29.0} = \frac{29,952.15}{29.0}$

$\boxed{P_2 = 1032.8 \text{ lbs.}}$

$-F_5 \cos 8°50' = 1032.8 \text{ lbs}$

$F_5 = \frac{-1032.8}{.9881} = -1045.2 \text{ lbs.}$

$C_5 = \frac{-1045.2}{2 \cos 20°20'} = \frac{-1045.2}{2(.9377)} = \boxed{-557.3 \text{ lbs}}$

CLASSIFICATION

JPL 0999 -5 APR 66

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

$-F_{5} \cos 3°50' + 37.0 = F_6 \cos 20°20'$

$F_6 = \frac{1069.8}{.9377} = 1140.9 \text{ lbs}$

$T_6 = \frac{1140.9}{2 \cos 3°50'} = \frac{1140.9}{2(.9881)} = \boxed{577.3 \text{ lbs}}$

$F_7 = -F_6 = -1140.9 \text{ lbs}$

$\therefore \boxed{C_7 = -577.3 \text{ lbs}}$

$-F_7 \cos 20°20' - 37.0 = F_8 \cos 8°50'$

$F_8 = \frac{1032.8}{.9881} = \boxed{1045.2 \text{ lbs}}$

$T_8 = \frac{1045.2}{2 \cos 20°20'} = \frac{1045.2}{1.8754} = \boxed{557.3 \text{ lbs.}}$

$F_8 \cos 8°50' = 1032.8$ CHECKS WITH P_2

THE TORQUE OF R_{FWD} ABOUT CTR LINE

$M_T = (485.7)(16) = 7771.2 \text{ in lbs}$

THE LOAD IN THE BRACINGS IS ALTERNATELY COMPRESSION AND TENSION.

$C_T = T_T = \frac{M_T}{8(14.5) \sin 20°20'} = \frac{7771.2}{8(14.5)(.347)}$

$\boxed{\pm 193.1 \text{ lbs}}$

CLASSIFICATION

JPL 0999 -S APR 66

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

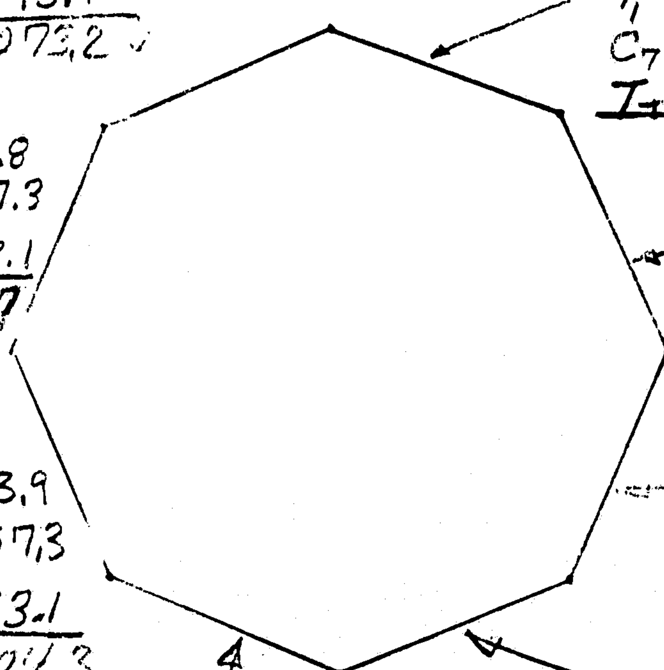
COMBINE THE AXIAL, TORSIONAL LOADS

$T_1 = 1689$
$T_6 = 577.3$
$C_4 = -193.1$
2073.2 ✓

$T_1 = 1689.0$
$C_7 = -577.3$
$T_4 \quad 193.1$
1304.8

$C_2 = -285.8$
$C_5 = -557.3$
$T_4 = 193.1$
-649.7

$C_2 = -285.8$
$T_8 = 557.3$
$C_4 = -193.1$
98.4



$C_3 = -253.9$
$C_8 = -557.3$
$C_4 = -193.1$
-1004.3

$C_3 = -253.9$
$T_8 = 557.3$
$T_4 \quad 193.1$
496.5 ✓

$C_9 = -269.9$
$T_6 = 577.3$
$T_4 = 193.1$
500.5 ✓

$C_9 = -269.9$
$C_7 = -577.3$
$C_4 = -193.1$
-1040.3 ✓

THE MAXIMUM COMPRESSION = -1040.3 lbs.
THIS GOVERNS THE DESIGN OF THE BRACINGS

SUPPOSE USE 1" × .045 INVAR. TUBING

CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

FOR 1"ϕ X .045" INVAR TUBE

$E = 21.0 \times 10^6$

$I = .0154$

CRITICAL LOAD

$$P_{CR} = \frac{\pi^2 E I}{L^2} = \frac{\pi^2 (21)(10^6)(.0154)}{29.84^2} = 3580 \text{ LBS.}$$

$$M.S. = \frac{3580}{1040.3} - 1 = \underline{\underline{2.44}}$$

THE SINGLE MAX TENSION IS 1689 # DUE TO AXIAL LOAD

FOR 50 G, IT WILL BE $1689 \times \frac{50}{10} = 8445$ #

$$\sigma_{max} = \frac{8445}{.135} = 62500 \text{ PSI}$$

$$F_{TU} = \frac{65000}{62500} - 1 = \underline{\underline{.04}}$$

THE MAX. COMPRESSION DUE SIDE LOAD

IS $-577.3 - 193.1 = -770.4$

FOR 50 G SIDE LOAD $= -770.4 \left(\frac{50}{3}\right) = -12850$ LBS

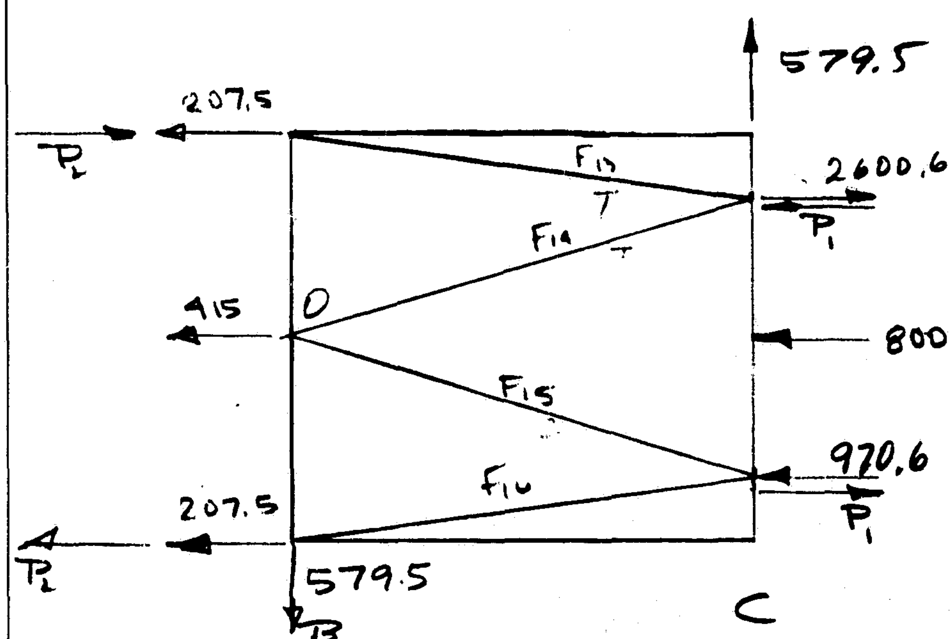
$$MS = \frac{3580}{12850} - 1 = \underline{\underline{-.72}}$$

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY	DATE	REPORT NO.
CHECKED BY	DATE	PROJECT

TITLE

SECTION B-C



NOTE: MOVE 800 lbs. FORCE DUE TO CAMERA DOWN TO THE ℄. ALSO HAVE TO ADD A MOMENT AT THIS PT. TO GET EQUIVALENT FORCES.

$(800)(23) = P_1 (20.5)$

$P_1 = 897.6$ lbs.

HORIZONTAL SHEAR

$2600.6 - 970.6 - 800 = 830$

DEVIDED INTO FOUR PARTS

$P_4 = \frac{830}{4} = 207.5$ lbs.

$M_0 = (579.5)(27.66) + 18{,}400 - (2600.6 + 970.6)(10.25)$

$= 34{,}429.0 - 36{,}604.8$

$= 2{,}175.8$ in-lbs

Thus $P_2 = \frac{2{,}175.8}{29.0}$

$P_2 = 75.0$ lbs.

CLASSIFICATION JPL 0999 -5 APR 66

PREPARED BY	DATE	JET PROPULSION LABORATORY	REPORT NO.
CHECKED BY	DATE	CALIFORNIA INSTITUTE OF TECHNOLOGY	PROJECT

TITLE

SOLVE FOR THE FORCES IN THE MEMBERS, REMEMBERING THAT THE F's ARE THE FORCES IN TWO DIMENSIONS.

$$F_{13} \cos 8°50' = 207.5 - 75.0 = 132.5$$

$$F_{13} = \frac{132.5}{.9881} = \underline{134.1 \text{ lbs.}}$$

$$F_{13} \cos 8°50' + F_{14} \cos 20°20' = 2600.6 - 400 - 897.6$$

$$F_{14} = \frac{1170.5}{.9377} = \underline{1248.2 \text{ lbs.}}$$

$$F_{14} \cos 20°20' + F_{15} \cos 20°20' = 415$$

$$F_{15} = \frac{-755.5}{.9377} = \underline{-805.7 \text{ lbs}}$$

$$F_{16} \cos 8°30' + F_{15} \cos 20°20' = 897.6 - 400 - 970.6$$

$$F_{16} = \frac{282.5}{.9881} = \underline{285.9 \text{ lbs}}$$

TO CHECK $F_{16} \cos 8°50 = 282.5$ lbs

Get $282.5 = 282.5$

THIS CHECKS.

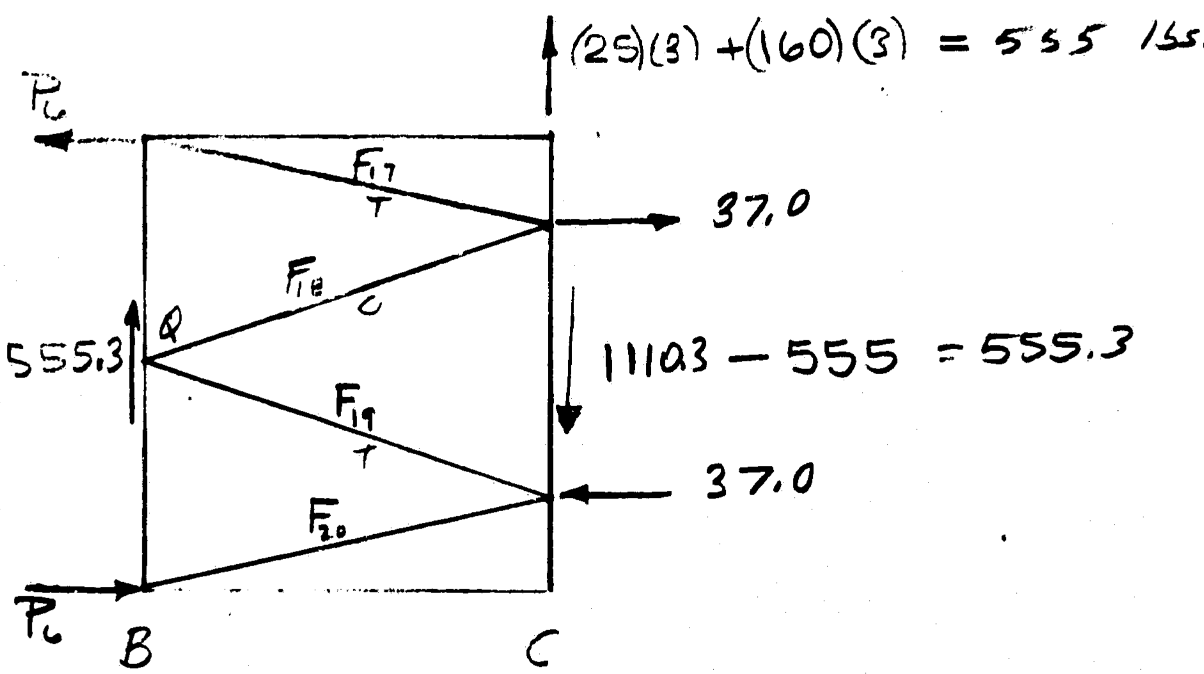
CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

SIDE LOAD



$$M_Q = (555.3)(27.66) + (37.0)(20.5) = 15{,}359.6 + 758.5$$
$$= 16{,}118.1 \text{ in - lbs.}$$

$$P_6 = \frac{16{,}118.1}{29.0} = 555.8$$

$$F_{17} \cos 8°50' = 555.8$$

$$F_{17} = \frac{555.8}{.9881} = 562.5 \text{ lbs,}$$

$$F_{17} \cos 8°50' + F_{18} \cos 20°20' = 37.0$$

$$F_{18} = \frac{-518.8}{.9377} = -553.3 \text{ lbs.}$$

$$F_{19} = -F_{18}$$

$$F_{19} = 553.3 \text{ lbs.}$$

CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

$F_{20} \cos 8°50' + F_{19} \cos 20°20' = -37.0$

$$F_{20} = \frac{-559.8}{.9881} = -562.5 \text{ lbs.}$$

CHECK $F_{20} \cos 8°50'$ SHOULD $= -555.8$

$-555.8 = -555.8$ CHECKS.

SOLVE FOR 3-D FORCES.

$$T_{13} = \frac{134.1}{2(.9377)} = \boxed{71.5 \text{ lbs.}}$$

$$T_{14} = \frac{1248.2}{2(.9881)} = \boxed{631.6 \text{ lbs.}}$$

$$C_{15} = \frac{-805.7}{2(.9881)} = \boxed{-407.7 \text{ lbs.}}$$

$$T_{16} = \frac{285.9}{2(.9377)} = \boxed{152.4 \text{ lbs.}}$$

$$T_{17} = \frac{562.5}{2(.9377)} = \boxed{299.9 \text{ lbs.}}$$

$$C_{18} = \frac{-553.2}{2(.9881)} = \boxed{-279.9 \text{ lbs.}}$$

$$T_{19} = \boxed{279.9 \text{ lbs.}}$$

$$C_{20} = \frac{-562.5}{2(.9377)} = \boxed{-299.9 \text{ lbs.}}$$

CLASSIFICATION

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO
CHECKED BY | DATE | PROJECT

TITLE

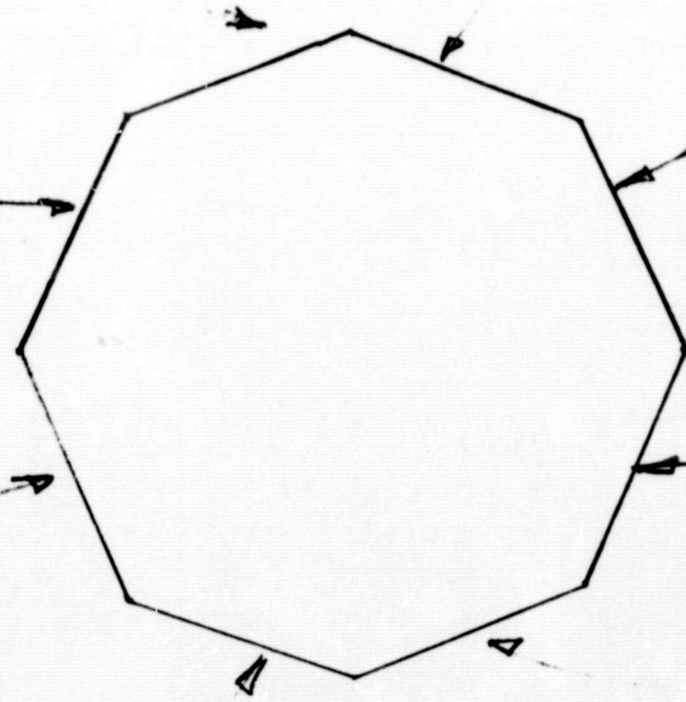
FOR TORSION SECTION IS SAME AS SECTION C-D

$T_{13} = 71.5$
$C_{18} = -279.9$
$T_T = 193.1$
-15.3

$T_{13} = 71.5$
$T_{19} = 279.9$
$C_T = -193.1$
158.3

$T_{14} = 631.6$
$C_{20} = -299.9$
$T_T = 193.1$
524.8

$T_{14} = 631.6$
$T_{17} = 299.9$
$C_T = -193.1$
738.4



$C_{15} = -407.7$
$C_{20} = -299.9$
$C_T = -193.1$
-900.7

$C_{15} = -407.7$
$T_{17} = 299.9$
$T_T = 193.1$
85.3

$T_{16} = 152.4$
$T_{19} = 279.9$
$T_T = 193.1$
625.4

$T_{16} = 152.4$
$C_{18} = -279.9$
$C_T = -193.1$
-320.6

MAX COMPRESSIVE LOAD = -900.7 lbs.

USING 1" x .045 INVAR TUBING

$$M.S. = \frac{3600}{900.7} - 1 = \text{HIGH}$$

CLASSIFICATION

JPL 0999 -5 APR 66

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO

CHECKED BY | DATE | PROJECT

TITLE

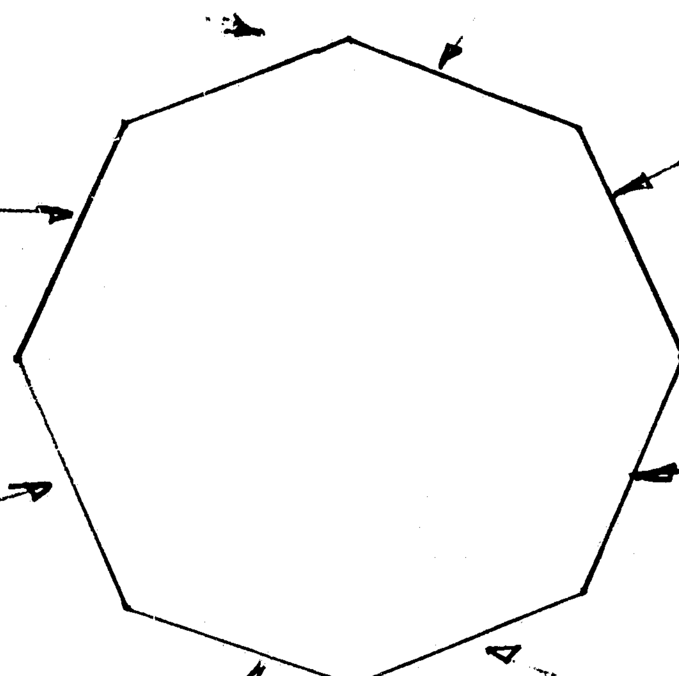
FOR TORSION SECTION IS SAME AS SECTION C-D

$T_{13} = 71.5$
$C_{18} = -279.9$
$T_T = 193.1$
-15.3

$T_{13} = 71.5$
$T_{19} = 279.9$
$C_T = -193.1$
158.3

$T_{14} = 631.6$
$C_{20} = -299.9$
$T_T = 193.1$
524.8

$T_{14} = 631.6$
$T_{17} = 299.9$
$C_T = -193.1$
738.4



$C_{15} = -407.7$
$C_{20} = -299.9$
$C_T = -193.1$
-900.7

$C_{15} = -407.7$
$T_{17} = 299.9$
$T_T = 193.1$
85.3

$T_{16} = 152.4$
$T_{19} = 279.9$
$T_T = 193.1$
625.4

$T_{16} = 152.4$
$C_{18} = -279.9$
$C_T = -193.1$
-320.6

MAX COMPRESSIVE LOAD = -900.7 lbs.

USING 1" x .045 INVAR TUBING

$$M.S. = \frac{3600}{900.7} - 1 = \text{HIGH}$$

CLASSIFICATION

JPL 0999 -5 APR 66

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PREPARED BY | DATE | REPORT NO.
CHECKED BY | DATE | PROJECT

TITLE

THE MAX. TENSION IS 631.6 #

FOR 50G, IT WILL BE $631.6\left(\frac{50}{10}\right) = 3160$ #

" $\phi \times .045$ INVAR TUBE

$$\sigma_{MAX} = \frac{3160}{.135} = 23400 \text{ PSI}$$

$$MS = \frac{65000}{23400} - 1 = \underline{\underline{1.78}}$$

FOR MAX. COMPRESSION IS $-279.9 - 193.1 = -473.0$ #

FOR 50G SIDE LOAD

$$\text{MAX. COMP.} = -473\left(\frac{50}{3}\right) = -7900 \text{ LBS}$$

$P_{cr} = -3600$ LBS

$$MS = \frac{3600}{7900} - 1 = \underline{\underline{-.544}}$$

CLASSIFICATION

JPL 0999 -5 APR 66